Oil Sands Monitoring

Core Biodiversity Monitoring - Benthic Macroinvertebrates Sample and Data Summary Report: 2011-2025



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Core Biodiversity Monitoring- Benthic Macroinvertebrates Sampling and Data Summary Report 2011-2025.

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Executive Summary

Benthic macroinvertebrates (BMI) are key components of riverine food webs, are comprised of insects, crustaceans, molluscs and worms, and exist in intricate communities of individuals called “assemblages”. By sampling BMI assemblages, along with water and sediment chemistry, habitat measurements, and other environmental variables, the core Oil Sands Monitoring (OSM) Benthic Macroinvertebrate Monitoring Program objectives include determining if changes in BMI communities are occurring, if there are linkages with oil sands development, and the extent of cumulative effects along the river course.

This report is provided as a summary of the data and sampling that has occurred under the OSM benthic monitoring program since the initial sampling in 2011. The intent is to update the data summary tables in this report on an annual basis as a tool for various stakeholders of the program as a succinct and accessible introduction to the BMI sampling regime. The report provides a detailed summary of how, where, and when sampling has occurred. Although the Introduction and Study Design sections describe the objectives and the study design in a general context, there is no analysis or interpretation included herein. Sampling methods are briefly described with links to Standard Operating Protocols. Data characteristics, processes, and timelines are described and links to data available online are provided as well as a list of related presentations and publications.

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1. Introduction

Benthic macroinvertebrates (BMI) are key components of riverine food webs, are comprised of insects, crustaceans, molluscs and worms, and exist in intricate communities of individuals called “assemblages”. Changes in benthic invertebrate assemblages are used world-wide in environmental monitoring programs of aquatic ecosystem health because they are 1) reliable short- and long-term indicators of human disturbance, 2) have limited mobility and thus integrate the effects of exposure to stressors, and 3) are easy to collect. By sampling BMI assemblages along with water and sediment chemistry, habitat measurements, and other environmental variables the core long-term Oil Sands Monitoring (OSM) Benthic Macroinvertebrate Monitoring Program can relate Pressures/Stressors of the existing OSM conceptual model to determine: 1) whether changes in BMI communities are occurring; 2) if there are linkages with oil sands development; and 3) the extent of cumulative effects along the river course.

For consistency we have chosen to refer to current environmental condition as the “Accumulated State” and current environmental condition in pre-defined reference sites as “Reference State” as defined in the Water Quality Monitoring Plan (Environment Canada, 2011a).

The objectives of this annual benthic macroinvertebrate data and sample summary report are to: 1) provide a summary of how, where, and when sampling has occurred in succinct and easily digestible format and 2) update annual sampling designs as approved through the Core Biodiversity Monitoring – Benthic Invertebrates work plan. Although the Introduction and Study Design sections describe the objectives and the study design in a general context, there is no analysis or interpretation included herein. Sampling methods are briefly described with links to Standard Operating Protocols. Data characteristics and processes are described and links to the sampled data available online are provided. Annual sampling efforts by region and site from 2011-2025 are summarized and provided in tables updated annually, (Tables 1, 2, 3 andTables A1a-d).

2. Study Design

The current OSM BMI adaptive and integrated monitoring design is based on the recommendations from the peer-reviewed 2018 Technical Report (Culp et al., 2018) findings and as reviewed through the annual work planning process. The current adaptive monitoring design was updated from the original design published in the 2011 Integrated Monitoring Plan for the Oil Sands (Environment Canada 2011a and b). However, it should be noted that the core Benthos Monitoring program is integrated with the other Surface Water Monitoring programs, including Water Quantity, Water Quality, and Fish Health. From the initiation of the program, in both the Athabasca River and its major tributaries, sampling has been based on a gradient design from upstream to downstream to allow detection of change and assessment of cumulative effects of multiple stressors on benthic macroinvertebrate assemblages. Factors considered in the design included whether the river reach is within a reference area (both outside and inside areas with exposure to natural bitumen), and location relative to municipal effluent inputs, oil sands activities, and other stressors (e.g., outfalls/discharges) that may contribute to cumulative effects.

The BMI program is not designed to identify or monitor specific point source releases, but rather the overall aquatic ecosystem health and cumulative effects of the Athabasca River and its major tributaries relative to Reference and Accumulated States (Environment Canada 2011a). However, benthic invertebrate community assessments can detect changes resulting from periodic short or long-term exposure to low-level contaminants not necessarily detected through routine water quality programs. These gradient designs are robust in nature so that if additional stressors are introduced in the future, minimal adaptation of the design would be required to continue to detect change and cumulative effects on benthic macroinvertebrate communities.

The program continues to employ an adaptive monitoring approach, consisting of core sampling sites that are monitored annually and rotational sites that are sampled less frequently. Over the past three years (2023-2025), monitoring efforts have been focused on areas where changes in benthic macroinvertebrate assemblages have been observed, with subsequent evaluation of potential drivers identified in the conceptual model, including both natural and anthropogenic factors. This targeted approach supports the assessments of change relative to reference conditions and facilitates the evaluation of cumulative effects. A detailed summary of the sampling achieved during this period is provided in Section 2.1.

A general description of the sampling designs and current monitoring phase for each subproject is provided

for context of the data and sampling summaries provided below.

Athabasca River Mainstem (Fig.1)

The integrated gradient style design used by the Mainstem Benthos biomonitoring program is based on accepted Environmental Effects Monitoring (EEM) study designs. ECCC has established 19 BMI gravel/cobble sites including Reference sites outside exposure to natural bitumen, Reference sites exposed to natural bitumen, Municipal Sewage Effluent (MSE) exposure sites, sites adjacent to Oil Sands Development activities, and sites located downstream of all human activities and considered Recovery areas. Not all sites are sampled each year, but a core set of sites are sampled annually with other sites sampled on a rotational basis. These areas have been sampled since 2011 to establish Reference and Accumulated State for indicators of BMI assemblage and structural change (Receptors in the Source-Pathway-Receptor conceptual model). Design of the Mainstem BMI monitoring program is integrated and similar to those for the core Water Quality and Fish Health Monitoring programs, if significant change is detected, investigation of drivers is used to identify associations of change.

In 2017/2018, three sites (M1, M2, M7) were suspended for several reasons. First, M1 was suspended because it was located on a gravel bar in the middle of the river and was therefore not directly comparable to the other sampling locations, which were associated with suitable gravel/cobble habitat along the shoreline. The M2 sampling site was suspended because it was located near the mouth of the Horse River and was therefore influenced by relatively unmixed water from that tributary, potentially confounding the relationship between water chemistry and the benthic macroinvertebrate community. Lastly, M7 was suspended because excessive sediment and silt accumulation rendered the gravel/cobble habitat unsuitable for sampling.

Lower Athabasca River (LAR) Tributaries (Fig. 2)

Within four of the major tributaries (Steepbank, Ells, Mackay and Firebag rivers) of the Athabasca River, an EEM gradient style design of 15-20 sites was used with replicate sites within river reaches with similar human disturbance levels, i.e., reference outside natural bitumen, reference inside natural bitumen, and up to 4 areas within a tributary with increasing percentage of land disturbance (i.e., test groups). The OSM tributary program, initiated in 2011, has established 132 sites distributed among the different reference and exposure areas, with, on average, 53 sites sampled annually. The sampling to date establishes Reference State as well as Accumulated State in the exposure areas against which current and future change will be assessed. Several other tributaries including Alice Creek and the McIvor River entering the Peace Athabasca Delta, in and around Wood Buffalo National Park, have also been sampled since 2012. In 2025, several new tributary sites were established to address specific concerns raised during the work planning process including two in the Tar River and one additional site in the lower Muskeg River.

***In Situ OSM Regions* (Fig. 3 and 4)**

The Peace River, Christina River and Cold Lake *in situ* Regions are in earlier stages of biomonitoring. Reconnaissance and initial sampling has occurred in these regions from 2016 – 2025. Building on work done to date, the program currently is focused on establishing Reference and Accumulated State for all *In Situ* areas. In the Christina River watershed, sampling continued in 2025, with sampling strategy of focusing on sites with fewer than 4 years of sampling along with a subset of core annual sites. The Hangingstone and Horse rivers are also sampled under the *in situ* program. In these two rivers, sampling was initiated in the fall after the 2016 Fort McMurray wildfire, with an average of 8 of the 16 sites sampled annually. Sampling in the Cold Lake Oil Sands Region started in the fall of 2023, and, to date, 10 sites have been established, with 7 sampled in 2025. Sampling in the Peace River Oil Sands Region was paused in 2021, and study design options are currently being developed. The study design for the core BMI program within the *in situ* areas of Christina River and Cold Lake include sites identified by the ICBM work plan team as sites of cultural significance to Indigenous communities within the core BMI study areas.

2.1. Intensive Study Design – 2022-2025

As indicated through the approved work plan for 2022-2025 a shift (or rotation) occurred during the most recent three years of sampling (2023-2025) in the Lower Athabasca River and its major tributaries (Steepbank, Ells, MacKay, and Firebag rivers). Results, previously reported for these areas, indicated significant differences in BMI community indicators, i.e., Receptors, within the areas of Oil Sands Development/Test Areas in comparison to Reference areas. Thus, the proposed work for the three-year period focused on intensive sampling in the areas of greatest benthic macroinvertebrate change. The objective was to evaluate the observed changes against anthropogenic stressors (Sources) in these reaches, while sampling long-term annual core sites in other areas to maintain continuity and

statistical power of that critical record, continue to establish baseline and accumulated state, and address natural variability:

- In the Mainstem Athabasca River, benthic macroinvertebrate samples and associated supporting variables were collected at 11 of the 19 sites each year, including 6 core annual sites (M0, M2A, M3, M3B, M4 and M9) and 5 intensive area sites (Northland, Sun-Up, Sun-Dn, M3C and M7B) within the reach where greatest change in benthic macroinvertebrate assemblages has been observed. Five of the core annual sites were paused during this 3-year period (M0A, M1A, M6, M7C, and M8) to allow increased efforts in the area of greatest change in benthic macroinvertebrate assemblages.

- In the Athabasca River tributaries, more benthic macroinvertebrate samples and associated supporting variables were collected in reaches of greatest change in benthic macroinvertebrate assemblages (i.e., the downstream test areas). As all intensive sites in each tributary could not be sampled annually, a rotational strategy for the intensive sampling was implemented by tributary. Through this three-year period, a minimal set of core annual sites were sampled in each tributary not in the annual intensive rotation to maintain the ability to assess annual variability. The rotation was as follows:

  - In 2023, the intensive monitoring was focused on the Steepbank River, with a total of 23 sites sampled along the entire longitudinal gradient. Previously, 13 sites are sampled annually on average in the Steepbank River (Table 1). The increased sampling effort in 2023 largely occurred in the three lower test areas with the addition of 5 new sites to increase site replication and statistical power, as well as sampling additional rotational sites in the upper reaches.
    In 2024, the intensive monitoring rotated to the Ells River with a total of 15 sites sampled, where, on average, 9 sites are sampled annually (Table 1). Although only 2 new sites were added to address longitudinal gaps, 5 of the rotational sites were sampled along with the core annual sites to increase site replication in the areas of greatest change.

  - In 2025, the intensive monitoring rotated to focus on both the MacKay and Firebag rivers. Two new sites in the Mackay River were added to address longitudinal gaps in the lower reaches, with a total of 12 sites sampled, 4 more than the average during the previous four years. Although no new sites were established in the Firebag River, 9 sites were sampled including three rotational sites to enhance the longitudinal coverage. Of note in 2025 was that conditions in many of the tributaries were not ideal, including logistical and water level issues. Thus, not all planned intensive sites were sampled in the Mackay and Firebag rivers. However, the sampling focus remained on sampling the areas of greatest change observed in benthic macroinvertebrate assemblages.

Thus, the overall sampling effort during the three-year intensive sampling was similar in the Athabasca River (11 sites) and only slightly reduced (14%) in the major tributaries when compared to previous annual sampling. Thus, sampling efforts primarily shifted to other locations rather increasing or decreasing sampling effort.

Table 1. Oil Sands Monitoring Program – Field sampling summary of the core long-term Benthos Monitoring program for all sampling areas from 2011-2025.

		Sampling Summary: 2011-2025					Exposure Categories Present					
	Sampling Area	Total # Sites	Year of First Sampling	# Years Sampled	Total # Samples (5/site for MS)	Avg # Samples / Year (excluding 2011 & 2020 & sand sites) in totals	Reference Outside Nat Bit	Reference Inside Nat Bit	Inside Natural Bit + MSE	Inside Natural Bit + MSE + OS Dev Activities	Inside Natural Bit + OS Dev Activities	Inside Natural Bit + Reduced OS Dev Activities (i.e., Recovery)
Athabasca River Mainstem	Lower Athabasca River Gravel Sites	19	2011	14	755	58	✓	✓	✓	✓	---	✓
	Lower Athabasca River Sand Sites	10	2011	5 (to 2015)	230	58	---	✓	✓	✓	---	✓
	Total	29	na	na	985	58						
Athabasca River & PAD Tributaries	Steepbank River	27	2011	14	163	13	✓	---	---	---	✓	---
	MacKay /Dover River	28	2011	14	143	11	✓	✓	---	---	✓	---
	Muskeg and JackPine	7	2011	14	34	3	---	✓	---	---	✓	---
	Ells River	22	2011	14	128	10	✓	✓	---	---	✓	---
	Firebag River	20	2011	14	102	8	✓	✓	---	---	✓	---
	Birch Mountains	26	2012	13	90	8	✓	---	---	---	---	---
	Tar River* 1st year - 2025	2	2025	1	2	2*	✓	---	---	---	✓	---
	Total	132	na	na	662	53						
In Situ/SAGD Areas	Horse River	7	2016	8	25	3	na - not yet classifed					
	Hangingstone River	9	2016	8	35	4						
	Christina River Watershed	45	2018	7	155	22						
	Cold Lake Oil Sands Area	10	2023	3	18	6						
	Peace River Oil Sands Area	19	2016	3	19	6						
	Total	90	na	na	252	42						
	Grand Total All Subcomponents	251	na	na	1899	153						

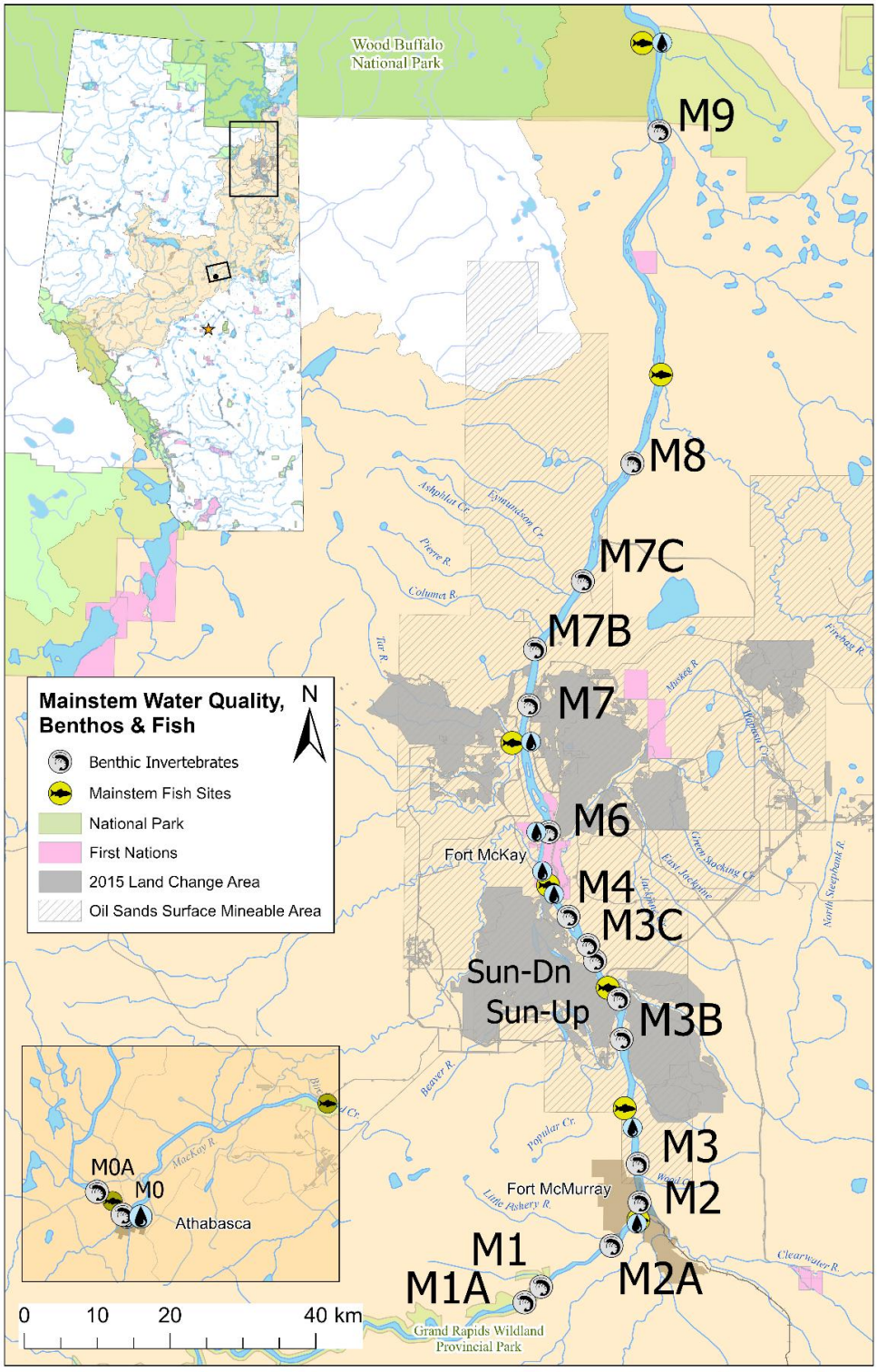


Figure 1. Map of current benthic macroinvertebrate monitoring sites in the mainstem of the Athabasca River of the surface mineable area of Athabasca Oil Sands Region. Core long-term Water Quality and Fish Health Monitoring program sampling locations are also indicated to depict the integrated nature of the Surface Water Monitoring program.

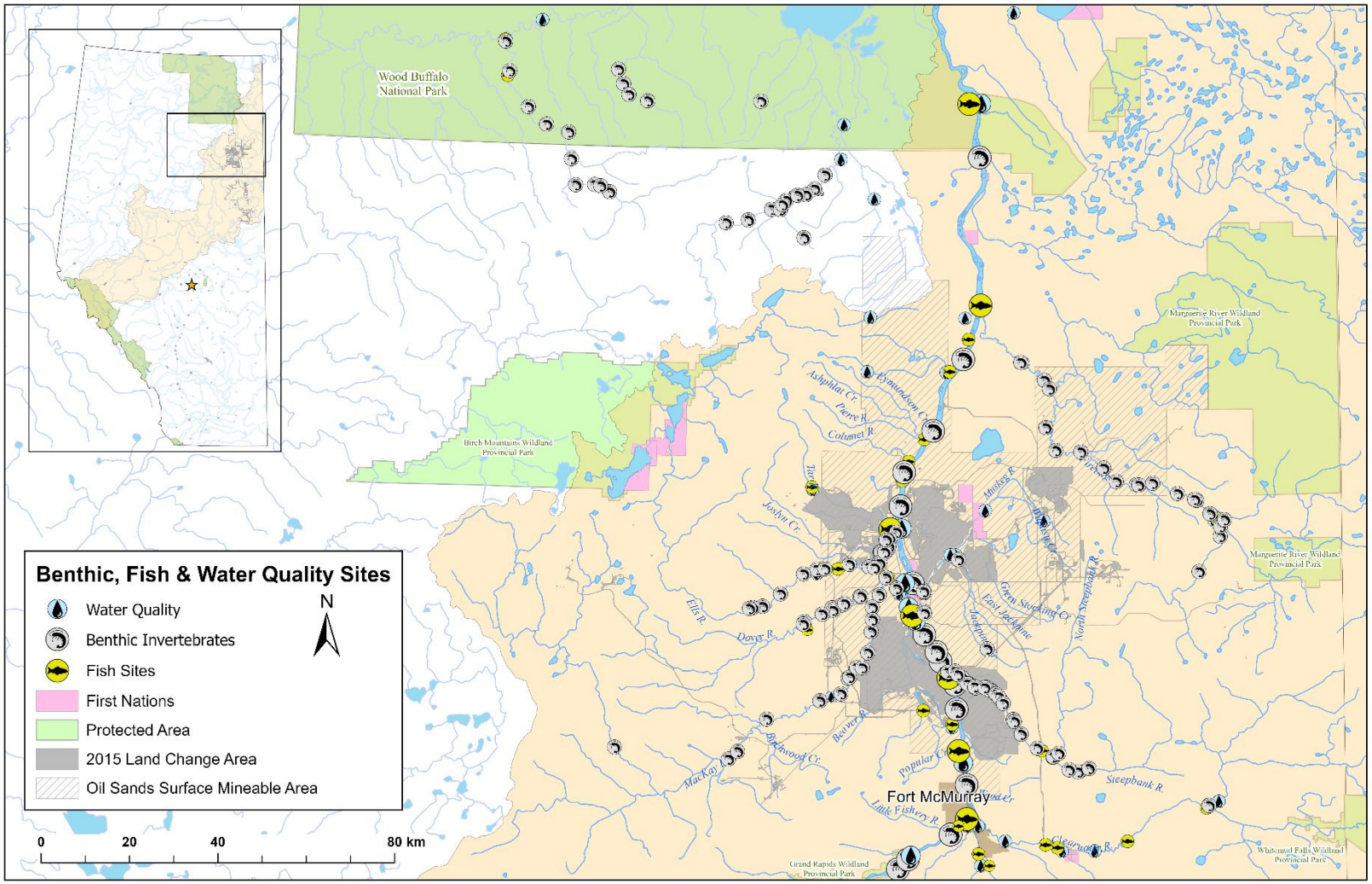


Figure 2. Map of current benthic macroinvertebrate monitoring sites in tributaries of the Athabasca River and Birch Mountains in the surface mineable area of Athabasca Oil Sands Region. Core long-term Water Quality and Fish Health Monitoring program sampling locations are also indicated to depict the integrated nature of the Surface Water Monitoring program.

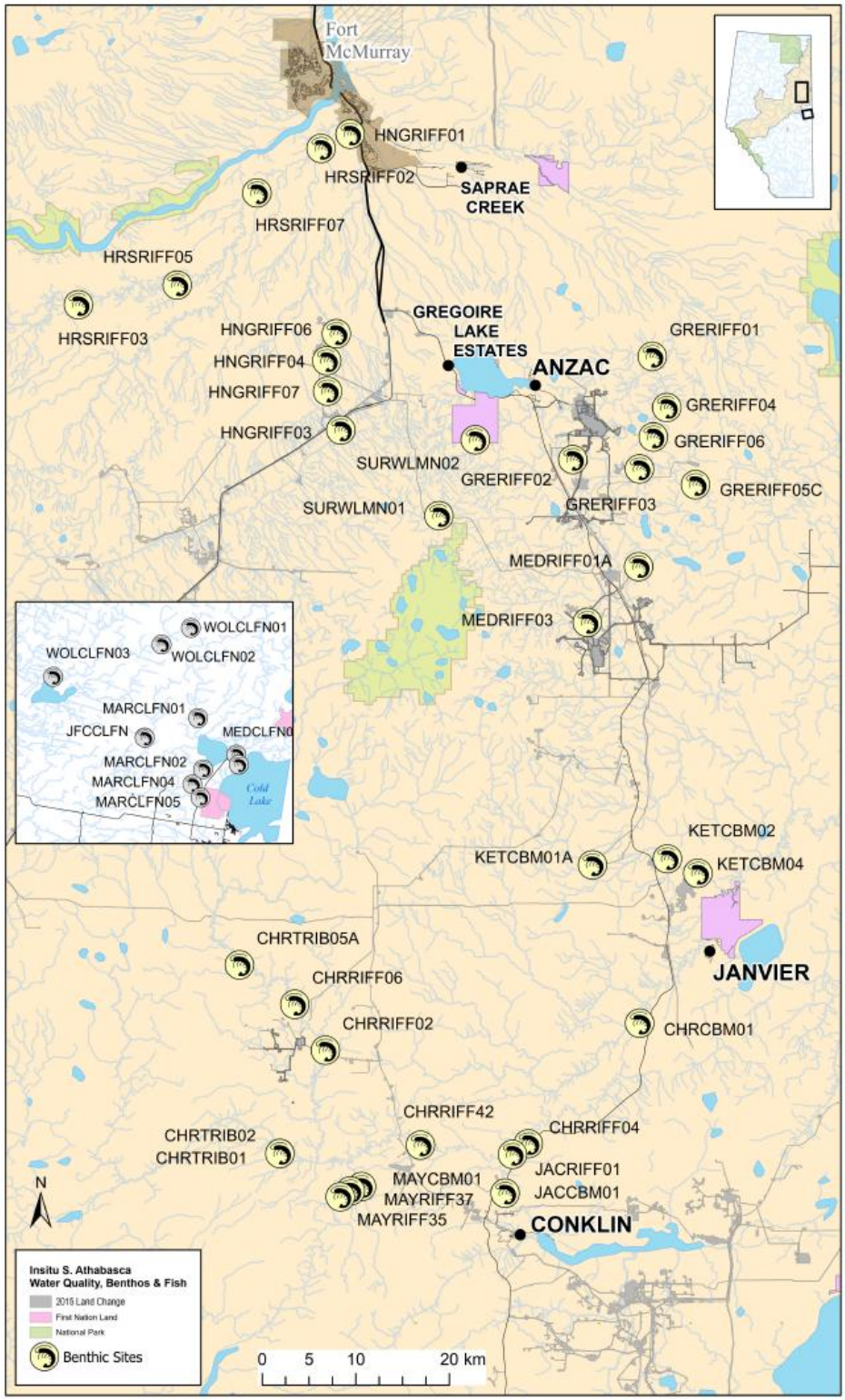


Figure 3. Map of current benthic macroinvertebrate monitoring sites within the In Situ areas of Athabasca Oil Sands Region in the Christina, Hangingstone, Horse rivers and in the Cold Lake Area. Core long-term Water Quality and Fish Health Monitoring program sampling locations are also indicated to depict the integrated nature of the Surface Water Monitoring program.

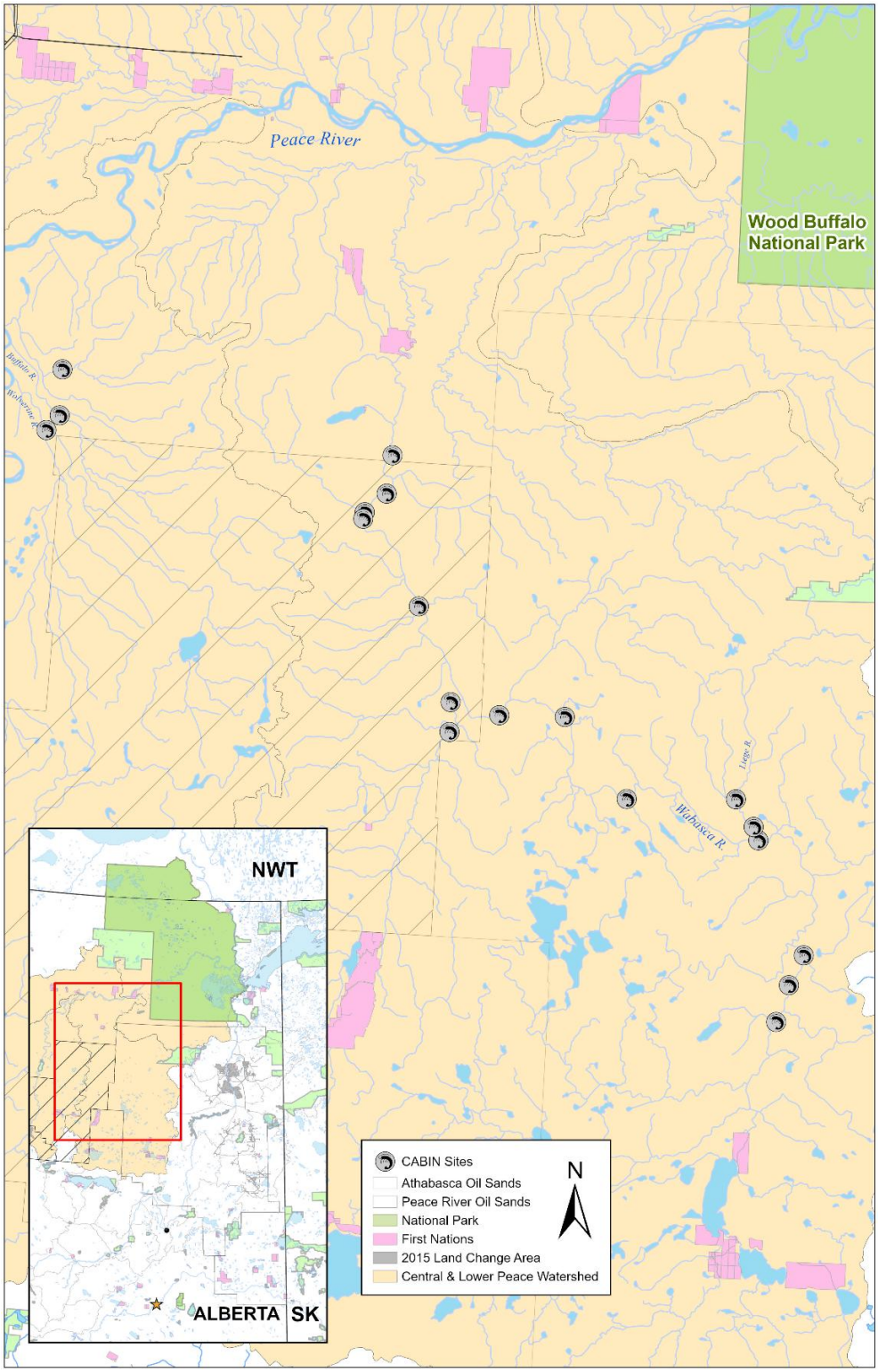


Figure 4. Map of benthic macroinvertebrate monitoring sites sampled between 2016-2019 in rivers within the Peace River Oil Sands Region.

3. Methods

Sampling is conducted once per year in the fall when water flows have stabilized, and benthic invertebrate communities are at their most diverse and sensitive to disturbance. Sampling includes the collection of benthic invertebrates using the kick sampling approach as described in the National CABIN methodology as well as habitat measures, such as slope, depth, velocity, periphyton (algal) biomass, and water and sediment quality as appropriate to the habitat and study specific objectives.

Water quality parameters routinely measured are based on the OSM recommended list in Appendix B of the Phase 1 water quality monitoring plan (Environment Canada 2011a). More specifically, water quality parameters include metals, nutrients, major ions, and polycyclic aromatic compounds (PACs), while sediment quality parameters include metals, mercury, and PACs. In addition, physico-chemical parameters include turbidity, dissolved oxygen, specific conductance, and temperature.

Semi-permeable membrane devices (SPMDs) are deployed at multiple sites in the Athabasca River and its tributaries in mid-August, a month prior to BMI sampling. SPMDs measure time-integrated dissolved PACs and provide critical data of chronic exposure concentrations to aquatic organisms during the critical fall life cycle for many benthic macroinvertebrates. Discrete water quality samples do not provide this type of exposure information.

The OSM benthic program generally follows CABIN field and laboratory protocols which can be found at the following link:

- Canadian Aquatic Biomonitoring Network resources - Canada.ca

The Mainstem Athabasca River benthic program follows a modified CABIN approach; details and protocols can be found here:

- Benthic Macroinvertebrate Biomonitoring Program: Mainstem Athabasca River - Federal Open Science Repository of Canada

In addition, both OSM BMI programs collect additional supporting measures relevant to benthic macroinvertebrate communities. The manual at the link below describes these additional protocols that are completed depending on the objectives of the adaptive monitoring program/sites for OSM: Standard Operating Procedures for Benthic Invertebrate Monitoring in Wadeable Streams of the Athabasca Oil Sands Region; additions to the national CABIN protocol - Datasets - Oil Sands Monitoring (alberta.ca)

Additional relevant SOPs can be found at the following links:

- Standard Operating Procedures for Water Quality Sampling - Datasets - Oil Sands Monitoring (alberta.ca)
- Standard Operating Procedures for Water Quality Data Management and Database Procedures - Datasets - Oil Sands Monitoring (alberta.ca)
- Standard Operating Procedures for Field Water Quality Sampling using Semi-permeable Membrane Devices (SPMDs) - Datasets - Oil Sands Monitoring (alberta.ca)
- Standard Operating Procedures for Management and Processing of Water Quality Data Collected using Semi-permeable Membrane Devices (SPMDs) - Datasets - Oil Sands Monitoring (alberta.ca)

Currently samples are processed and analyzed at the following laboratories:

- Water quality samples are analyzed at several laboratories including ECCC NLET laboratories for nutrients (Saskatoon), dissolved and total metals, major ions and physicals (Burlington). Polycyclic aromatic compounds (PACs) are analyzed at SGS AXYS laboratories in Victoria.
- Bed sediment samples are analyzed at NLET (Burlington) for extractable metals, mercury, carbon, nitrogen, and moisture and for PACs at SGS AXYS laboratories in Victoria.
- Benthic macroinvertebrate sample processing and identification are completed under contract by Society of Freshwater Science certified taxonomists. As per the CABIN National program and laboratory manual, a subset of samples are verified by the ECCC National CABIN taxonomist.

4. Data Characteristics and Availability

All data collected through the OSM BMI programs are uploaded, verified, and managed in ECCC water quality and biomonitoring relational databases. Database

protocols are provided at the links above and include routine back up processes on secure servers. These databases are considered the authoritative and originating source for OSM BMI data. Any updates, additions or QA/QC processes which occur within these databases are tracked. The most recent data files are uploaded and replace previous files on ECCCs Open data as described below. As such, users of the data should extract the most recent data files available.

Data is available on ECCC Open Data Portal (http://donnees.ec.gc.ca/data/substances/monitor/benthic-invertebrates-oil-sands-region/) and is current to all data available.

Data is uploaded to the ECCC Open Data portal as data becomes available in the respective databases. The schedule for data upload to the ECCC Open Data Portal for the BMI is between June – December for samples collected the previous fall, e.g., for samples collected in fall of 2025, all data is expected to be available by December of 2026. This schedule is based on the expected date of receiving the data from the specific laboratory. In some cases, there have been data delays from the laboratories. However, each new data upload to the Open Data portal has all that is currently held in the database.

Specific data requests for unverified data or specific data formats are filled upon request. Over 45 such individual requests since 2021 have been provided for OSM related data to Provincial and Territorial partners, consultants, universities, and communities.

5. Project Sampling Summaries 2011-2025

Monitoring design for the OSM Benthic Macroinvertebrate (BMI) monitoring program from 2011–2025 have been adapted on an annual basis and originated from the recommendations in the integrated monitoring plan document (Environment Canada, 2011). Subsequent revisions to the sampling locations and intensity were based on the recommendations after a comprehensive peer-review of the program and results (Culp et. al, 2018). In addition, an annual detailed monitoring schedule with a list of the planned sites to be sampled has been developed, reviewed, and approved through the OSM work planning process.

In all years, the sampling sites that were planned for the Athabasca River have been successfully completed. Similarly, all tributary sampling sites planned have been completed in most years. However, depending on river conditions and access at the time of sampling (e.g., high water, beaver dam activity, anchor ice on stream bed, etc.) some sites may not have been sampled or nearby sites in the same zone (Reference or Test region) may have been sampled as an alternative. Sampling has occurred consistently within a 4-week period, between mid-September to mid-October. Samples were not collected in 2020 due to the suspension of sampling because of the global pandemic.

Over the 14 years of the OSM macroinvertebrate biomonitoring program a total of 1,899 BMI and supporting water and sediment quality samples were collected from 250 sites in 12 distinct basins, rivers, or areas (Table 1, Tables A1a-d). On average, over 150 samples were collected each year. Sampling in the Athabasca River and its major tributaries (Steepbank, MacKay, Muskeg, Ells, and Firebag rivers) was the priority in the earlier years, starting with 30 sites sampled as a pre-OSM pilot project in 2011. In 2012, an additional 20 sites were established and sampling in the Birch Mountains area was initiated as pre-development reference sites. During the first 2-4 years of sampling, further sites were established to fill study design gaps. As well, several sampling approaches (i.e., mesh size, sampling device, and artificial substrates), and additional response variables including periphyton and sestonic algal biomass, environmental ‘omics’, stable isotopes and ecosystem function measures were or are currently being evaluated (Table 4 in Environment Canada, 2011; Culp et. al., 2018; Culp et. al., 2021). From 2017 (i.e., after the water rationalization exercise was completed during a workshop in November of 2016, Cooke et. al., 2018) to 2022 sampling effort and approaches have remained consistent. In a typical year, 11 of the 19 sites are sampled in the Athabasca River and 45 of the 128 sites established in the tributaries. In 2023-2025 the program in the Athabasca River and its major tributaries rotated to intensive sampling areas of greatest change detected in benthic macroinvertebrate communities (see summary in Section 2.1)

For the Athabasca River and its major tributaries, reference and exposure categories have been defined as in Culp et. al., (2018). In the Athabasca River (Table 1,Table A1a), sites are categorized in a gradient from upstream to downstream as, 1) Reference Outside Exposure to Natural Bitumen, 2) Reference Inside Exposure to Natural Bitumen, 3) Municipal Sewage Effluent (MSE) site with Inside Exposure to Natural Bitumen + high exposure to Municipal Sewage Effluent (MSE), but no oil sands development exposure, 4) Oil Sands Development sites with Inside Exposure to Natural Bitumen + moderate MSE + high exposure to OS

Development activities, and 5) Recovery sites with Inside Exposure to Natural Bitumen + moderate MSE + low exposure to OS Development activities. Sites have been added or relocated based on new information and not all sites are sampled every year, but since 2012 at least one site from each category has been sampled annually for assessment of cumulative effects (Appendix Table A1a). Additionally, during 2011-2015, as part of the investigation of sampling available benthic macroinvertebrate habitats, sand habitats were sampled at 10 sites in conjunction with the gravel cobble areas in the Mainstem of the Athabasca River (Table 1, Table A1a).

In the LAR tributaries, sites are similarly categorized as, 1) Reference Outside Exposure to Natural Bitumen, 2) Reference Inside Exposure to Natural Bitumen, and 3) Inside Exposure to Natural Bitumen + Exposure to increasing OS Development activities. Sites with exposure to OS Development activities are further identified as distinct test categories (1-4) depending on levels of exposure as defined by % land disturbance, % active lease, and location relative to the Oil Sands Mineable Area, and OS development footprint/activities in the upstream catchment (Glozier and Ritcey 2023). Depending on level of OS development, not all categories of sites are present in all basins (Table 1). The sampling effort for the study has been stratified equally between reference (50.2%) and exposure (49.8%) areas (Table 2). Within a stream, samples have been stratified as close to proportional to the available river distance and accessible sampling sites within a category as feasible. Low and high-water years have made annual sampling of some sites inaccessible, but a focus was placed on ensuring at least several sites within each category were sampled each year for assessment of cumulative effects along the river gradient (Appendix Table A1b).

At the conclusion of the final year (2025) of the intensive study in the Athabasca River and Athabasca River tributaries all sites were reviewed in detail to inform future monitoring designs. Six types of sites based on study design objectives and site status were defined. Each site was reviewed in detail with site specific knowledge and assigned one or more of these types (Tables A1a and A1b). The site categories were defined as follows:

- Core Annual sites: these sites are sampled annually, sampling design includes 2-3 replicate sites/ reference or test category, are longitudinally separated, and have been sampled consistently in the last 5 years.
- Rotational sites: these sites are additional replicates within a reference or test category, considered for sampling in years with unusual conditions or specific monitoring questions in the specific tributary. In addition, there are rotational sites in remote areas (i.e., Birch Mountains) which are sampled every 2-3 years to track changes through time.
- Intensive Study sites: these sites are added in specific years to enhance replication and to address specific questions e.g., during the 2023-2025 intensive sampling program.
- Alternative sites: these sites are within the same category, are in close proximity to a core annual site longitudinally and are listed as an alternative for circumstances where the targeted annual or rotational site cannot be sampled.
- Suspended Sites: these sites have not been sampled in recent years due to various factors such as inappropriate habitat or inaccessibility and are thus not recommended for future sampling.
- Establishing Reference/ Accumulated State; in the Athabasca River tributary area: these sites are new sites which have been added at request of SW TAC to establish current reference or accumulated state. As of fall 2025, three sites in the Athabasca River tributary area are in this category, two in the Tar River and an additional site in the lower Muskeg River. All sites in the in-situ areas, including the Christina River Watershed and Cold Lake Oil Sands Area, are also at this phase of evaluation.

Table 2. Oils Sands Monitoring Program – Field sampling summary of the core long-term Benthos Monitoring program by exposure category for tributaries to the Athabasca River and Peace Athabasca Delta by exposure category from 2011-2025.

	Total number of samples by Tributary and Exposure Category										
	Birch Mtns	Dover	MacKay	Ells	Firebag	Steepbank	Musk/Jack*	Tar	Total	%	
Reference - Outside Exposed Deposit	90	9	42	26	42	47	---	1	257	38.8%	50.2%
Reference - Inside Exposed Deposit	---	21	---	21	27	---	6*		75	11.3%	
Inside Exp Dep + OSM Test Group 1	---	---	26	31	33	25	6*	1	122	18.4%	49.8%
Inside Exp Dep + OSM Test Group 2	---	---	45	25	---	27	22		119	18.0%	
Inside Exp Dep + OSM Test Group 3	---	---	---	25	---	37	---		62	9.4%	
Inside Exp Dep + OSM Test Group 4	---	---	---		---	27	---		27	4.1%	
Total number of samples	90	30	113	128	102	163	34	2	662	100%	

For the Athabasca mainstem there are 11 core annual sites, 5 intensive study sites and 3 sites that have been suspended (Table A1a).

For the Athabasca River tributaries, details are also provided for each site in the Appendix tables (Table A1b). However, as there are over 130 sites, to aid in future study design considerations, we have summarized these sites by categories into two additional tables. First, for each major tributary, the number of sites in each of the above categories is summarized by river site definitions (Table 3). Overall, there are 44 core annual sites identified, 67 rotational/alternate sites, 10 sites which were added during the intensive study period, 8 that have been suspended and 3 that were added in 2025 and are currently classified as establishing reference/ accumulated state. Secondly, for the 44 core annual sites from all major tributaries, the distribution among the 6 exposure categories is provided (Table 4). Close to 40% of the core annual sites are in a reference category, leaving approximately 60% of sites spread out among the various test categories. It should be noted that not all categories have an equal number of accessible sites, in large part, because longitudinal river distance within a category as well as accessibility via helicopter differs among the category reaches. Finally, not all categories exist in a tributary (Table 4). Within these limitations, core annual sites have been selected to provide a robust, equally weighted study design for ongoing annual sampling (Fig.5).

In 2016 standardized OSM CABIN sampling was expanded to several *in situ* Oil Sands Regions including in the Peace River Oil Sands Region and the Horse and Hangingstone rivers near Fort McMurray (Table 1, Table A1c and d). A total of 19 sites were sampled once in the Peace River Region over a 3-year period. Although sites sampled were in gravel/cobble streams and rivers, the dominant habitats adjacent to operating facilities are slow flowing streams with fine sediments and wetlands. Sampling was suspended in the Peace River Region after 2019 to allow information to be gathered, such as land use, land disturbance, and aquatic habitat characteristics to allow appropriate sampling designs and study objectives to be developed. Once clear objectives and priority areas were established, sampling was planned to resume upon work plan approval. The Horse and Hangingstone rivers were first sampled in the fall of 2016, post Fort McMurray Wildfire, and sampling has continued in these two basins in a gradient design upstream and downstream of *in situ* operations.

In 2018, (Table 1, Table A1c) after work plan approvals, sampling in the Christina River Watershed was initiated to expand the OSM biomonitoring program to the *in situ* Regions south of Fort McMurray. The initial design was based on resampling sites from five streams that have historic BMI and water quality data through a previous study focused on effects of forestry in the mid to late 1990s. The TROLS (Terrestrial and Riparian Organisms, Lakes, and Streams) stream component was led by ECCC and included sampling of 4 sites in an upstream/downstream gradient design from each of the five major tributaries to the Christina River (Meadow, Cottonwood, Pony and Waddell creeks and the Kettle River). At the time of the TROLS study, there was minimal oil sands related activity in these basins, thus making the TROLS data set a unique opportunity to compare pre-OSM "Historic State" within this i*n situ* Region with current conditions. With the objective of establishing Reference and Accumulated State (Environment Canda 2011a) for this Region, in 2018 and 2019, a total of 12 sites were re-established among the five TROLS streams and an additional 8 sites

Table 3. Oils Sands Monitoring Program – Field sampling summary by exposure category for tributaries to the Athabasca River and Peace Athabasca Delta by exposure category from 2011-2025.

		Site Categories - =Study Design Objectives				
	Total # Sites	Core Annual	Rotational/Alternate	Suspended	Estab. Ref-Acc State	Intensive Study
Steepbank River	**27**	12	8	2	0	5
MacKay /Dover River	**28**	9	15	1	0	3
Muskeg and JackPine	**7**	2	2	2	1	0
Ells River	**22**	12	6	2	0	2
Firebag River	**20**	9	10	1	0	0
Birch Mountains	**26**	0	26	0	0	0
Tar River	**2**	0	0	0	2	0
Total	**132**	44	67	8	3	10

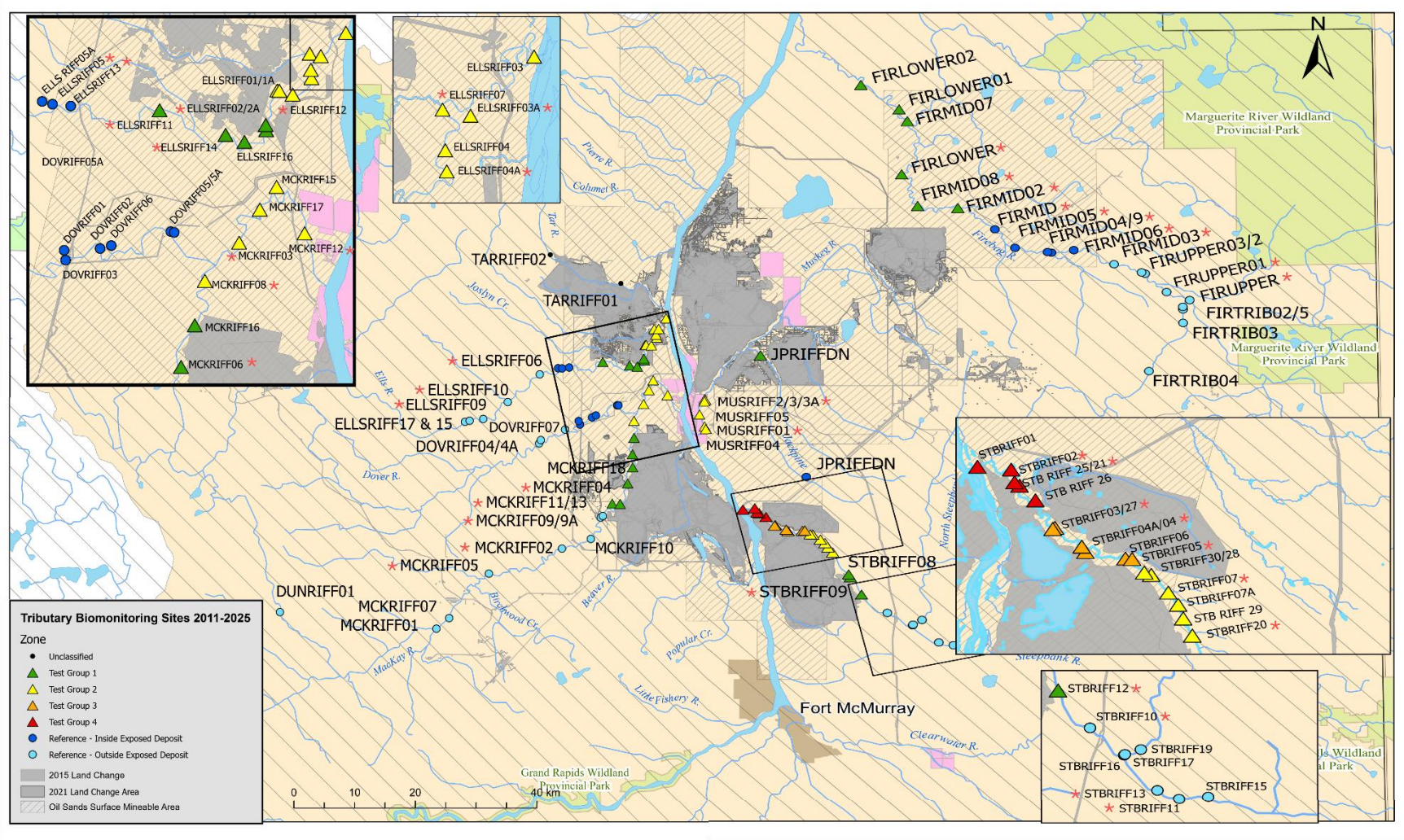


Figure 5. Map of current (improve quality) benthic macroinvertebrate monitoring sites in tributaries of the Athabasca River and Birch Mountains in the surface mineable area of Athabasca Oil Sands Region. Exposure categories are differentiated within a tributary by colour/symbols (see legend) and the core annual sites as described above and listed in Table A1b, are indicated by an * next to the site name.

in the Gregoire and upper Christina rivers. No sampling occurred in 2020 due to the global pandemic but since then an additional 25 sites have been established: the number of samples per site ranges from 1-7. As of 2025, 34 of the 45 sites (75%) have at least 3 samples but only 9 sites have >4 samples over the 7 years of sampling. Thus, establishing Reference and Accumulated State in the Christina River Watershed is still underway through ongoing data analysis and upcoming reporting. The focus of 2025 sampling was to increase sampling frequency at sites with < 3 years of sampling.

In 2023, sampling *in situ* areas expanded to the Cold Lake Oil Sands Area (Table 1, Table A1c). To date 10 sites have been established with 4 sites being sampled annually and the other 6 sites sampled once.

Table 4. Oils Sands Monitoring Program – Field sampling summary by exposure category for tributaries to the Athabasca River and Peace Athabasca Delta by exposure category from 2011-2025.

		Core Annual Site Categories - Reference/ Test					
	# Core Annual Sites	#Reference Outside Sites/yr	#Reference Inside Sites/yr	Test 1	Test 2	Test 3	Test 4
Steepbank River	12	3	na	2	2	3	2
MacKay /Dover River	9	3	0 (Dover)	3	3	na	na
Muskeg and JackPine	2	na	0 (Jackpine)	na	2	na	na
Ells River	12	3	2	3	2	2	na
Firebag River	9	3	3	3	na	na	na
Birch Mountains	0	0	na	na	na	na	na
Tar River	0	0	na	0	na	na	na
Total	44	12	5	11	9	5	2
Pecentage		27%	11%	25%	20%	11%	5%

6. Reporting - Primary Publication List and Select Presentations

Since the start of OSM, presentations and publications from the benthic macroinvertebrate OSM program have been produced and shared through peer-reviewed journal publications, technical reports, workshops, and conferences. A list of these reporting products is provided below with links to online sources where available. In addition, copies of key presentations provided by the study team at the 2020 and 2023 OSM work planning and Surface Water Technical Advisory Committee meetings have been provided in PDF form in Appendix B.

6.1. Publications

GLOZIER, N.E., R. B. BRUA, A. RITCEY, J. HANISH, K HYNES. 2025. Core Biodiversity Monitoring- Benthic Macroinvertebrates Sampling and Data Summary Report 2011-2024. Oil Sands Technical Report Series.49p.https://osmdatacatalog.alberta.ca/pubdata/bmi-data-summary-report2011-2024

LAU, D.C.P, R.B. BRUA, W. GOEDKOOP, & J.M. CULP. 2023. Fatty-acid based assessment of benthic food-web responses to multiple stressors in a large river system. *Environmental Pollution* 337: 122598 https://doi.org/10.1016/j.envpol.2023.122598

KLEMT, W.H., R.B. BRUA, J.M. CULP, K. HICKS, B.B. WOLFE, & R.I. HALL. 2021. Evaluating Lower Athabasca River sediment metal concentrations from Alberta Oil Sands Monitoring programs using pre-development baselines. *Environmental Science & Technology* 55: 8817-8828 https://doi.org/10.1021/acs.est.1c01761

CULP, J.M., DROPPO, I.G., DI CENZO, P.D., ALEXANDER-TRUSIAK, A., BAIRD, D.J., BICKERTON, G., BELTAOS, S., BONSAL, B., BRUA, R.B., CHAMBERS, P.A., DIBIKE, Y., GLOZIER, N.E., KIRK, J., LEVESQUE, L., MCMASTER, M., MUIR, D., PARROTT, J., PETERS, D.L., PIPPY, K. & J.W. ROY. 2021. Ecological effects and causal synthesis of oil sands activity impacts on river ecosystems: water synthesis review. *Environmental Reviews* 29: 315-327. https://doi.org/10.1139/er-2020-0082

CULP, J.M., R.B. BRUA, E. LUIKER & N.E. GLOZIER. 2020. Ecological causal assessment of benthic condition in the oil sands region, Athabasca River, Canada. *Science of the Total Environment* 749: 141393 https://doi.org/10.1016/j.scitotenv.2020.141393

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and Alberta Environment and Parks. 46 pp. os-ts-water-11-water-component-overall-synthesis-report.pdf (alberta.ca)

CULP, J.C., GLOZIER, N.E., BAIRD D.J., WRONA, F.J., BRUA, R.B., RITCEY A.L., PETERS D.L., CASEY. R., CHOUNG, C.B., CURRY, C.J., HALLIWELL, D., KEET, E., KILGOUR, B., KIRK, J., LENTO, J., LUIKER, E. & C. SUZANNE. 2018. Assessing ecosystem health in benthic macroinvertebrate assemblages of the Athabasca River main stem, tributaries, and Peace-Athabasca Delta. Oil Sands Monitoring Technical Report Series No. 1.7. Environment and Climate Change Canada and Alberta Environment and Parks. 82 pp. os-ts-water-17-benthos.pdf (alberta.ca)

6.2. Presentations

GLOZIER, N.E.**,** R.B. BRUA, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2025. Biomonitoring OSM program design and adaptation in the Tributaries. Invited presentation at 2025 COSIA Water, Tailings and Land Science Workshop October 21 2025 (Virtual).

CHAN, C., **R.B. BRUA**, E.M. KRYNAK, & A.G. YATES. 2025. INTERANNUAL VARIATION OF BENTHIC MACROINVERTEBRATE COMMUNITIES AT REFERENCE SITES ALONG THE ATHABASCA RIVER. SOCIETY OF CANADIAN AQUATIC SCIENCES MEETING, 19-22 FEBRUARY 2025, HAMILTON, ON, CANADA

GLOZIER, N.E.**,** R.B. BRUA, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2024. OSM Benthic Invertebrate Monitoring. Aquatic Reporting Workshop Lac La Biche, AB October 16-17 2024.

GLOZIER, N.E.**,** R.B. BRUA, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2024. OSM Benthic Invertebrate Communities – July 11, 2024 Update. SW TAC Meeting July 11 2024 *(Virtual).*

GLOZIER, N.E., & A. L, RITCEY. 2024. Assessing Shifts in Invertebrate Communities with Gradient Design; Steepbank River, Alberta. Invited presentation at the Bow River Basin Council meeting 25 March 2024 *(Virtual).*

GLOZIER*, N.E.**,** R.B. BRUA*, A. RITCEY, J. HANISCH*, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrates – Thoughts on limits of change. Surface Water Technical Advisory Committee Meeting, 22-24 August 2023, Calgary, Alberta. *Co-presenters

GLOZIER*, N.E.**,** R.B. BRUA*, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrate Communities 2012 to 2023. Water Technical Advisory Committee Meeting, 24-25 July 2023, Calgary, Alberta. *Co-presenters

GLOZIER, N.E., & A. L, RITCEY. 2023. Shifts in Invertebrate Communities; Linkages to Stressor within the Oil Sands Area of Canada – Steepbank River, Alberta. International Society for Ecological Monitoring, May 2023, Toronto, Ontario

BRUA, R.B**.,** J.M. CULP, D.J. BAIRD, N.E. GLOZIER, M.E. MCMASTER, J.L. PARROTT, C.J. BENNETT, R. CASEY, C.B. CHOUNG, T. CLARK, C.J. CURRY, M. EVANS, R.A. FRANK, D. HALLIWELL, E. KEET, H. KEITH, B. KILGOUR, J. KIRK, J. INGS, J. LENTO, E. LUIKER, D.L. PETERS, A.L. RITCEY, C. SUZANNE , G.R. TETREAULT, & F.J. WRONA. 2022. Assessment of biological condition: Lower Athabasca River tributaries and mainstem. 2022 COSIA Mine Water Management Workshop, 18-19 October 2022, Edmonton, Alberta, Canada. Virtual presentation

BRUA, R.B. & K. HYNES. 2021. Assessment of benthic condition in the Athabasca River – Update on recent data analysis. 2021 COSIA Mine Water Management Workshop, 30 November – 1 December 2021. Virtual conference.

KLEMT, W.H., R.B. BRUA, J.M. CULP, K. HICKS, B.B. WOLFE, & R.I. HALL. 2021. Evaluating lower Athabasca River sediment metal concentrations from Alberta oil sands monitoring programs using pre-development baselines. 2021 COSIA Mine Water Management Workshop, 30 November – 1 December 2021. Virtual conference.

KLEMT, W.H., R.B. BRUA, J.M. CULP, K. HICKS, B.B. WOLFE, & R.I. HALL. 2021. Evaluating lower Athabasca River sediment metal concentrations from Alberta oil sands monitoring programs using pre-development baselines. Society of Environmental Toxicology and Chemistry (SETAC) North America 40th Annual Meeting, 14-18 November 2021. Virtual conference.

RITCEY, A. L., & J. HANISCH. 2021. Monitoring with the CABIN Wadeable Streams Protocol in the Oil Sands Regions of Alberta. Foothills Research Institute workshop on CABIN sampling. 2021. Calgary, AB.

BRUA, R.B**.** & K. HYNES. 2021. Oil sands monitoring: Benthic macroinvertebrates – Mainstem Athabasca River. Surface Water Technical Advisory Committee

Oil Sands Monitoring Meeting, 14 September 2021. Virtual.

BRUA, R.B. 2021. Oil sands monitoring using benthic macroinvertebrates. EPB-STB Oil Sands Monitoring Workshop, 4 August 2021. Virtual.

BRUA, R.B., J.M. CULP, & N.E. GLOZIER. 2020. Aquatic ecosystem health monitoring: Benthic macroinvertebrates. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta.

Glozier, N.E. A. Ritcey, K. Hynes and J. Hanisch 2020. Aquatic Ecosystem Health Monitoring – Benthic Macroinvertebrates. OSM Area – FMM Tributaries; SAGD Areas, South of FMM, Peace River and Cold Lake. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta.

RITCEY, A. L., & N.E. GLOZIER. 2019. Invertebrate Community Shifts in Streams Exposed to Natural Bitumen and Oil Sands Surface Mining in the Athabasca Oil Sands Area, Alberta, Canada. Society for Freshwater Science Annual Meeting. 2019. Salt Lake City, Utah.

RITCEY, A., & N.E GLOZIER. 2018 (POSTER). Patterns in riverine benthic communities from reference and potentially impacted areas in the Athabasca oil sands area, Alberta, Canada. Canadian Ecotoxicity Workshop. Vancouver, BC

BRUA, R.B., J.M. CULP, D.J. BAIRD, N.E. GLOZIER, M.E. MCMASTER, J.L. PARROTT, C.J. BENNETT, R. CASEY, C.B. CHOUNG, T. CLARK, C.J. CURRY, M. EVANS, R.A. FRANK, D. HALLIWELL, E. KEET, H. KEITH, B. KILGOUR, J. KIRK, J. INGS, J. LENTO, E. LUIKER, D.L. PETERS, A.L. RITCEY, C. SUZANNE , G.R. TETREAULT, & F.J. WRONA. 2017. Assessment of biological condition: Lower Athabasca River tributaries and mainstem. CABIN Science Forum, 28 February-1 March 2017. Edmonton, Alberta, Canada.

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Appendix A

Table A1a. Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Mainstem Lower Athabasca River benthic macroinvertebrate monitoring program. Five replicate BMI samples taken at each site. X= Sampled in gravel substrate; XX = sampled in both gravel and sand substrates. *Exposure categories as in Culp et al., (2018).

Region	Site Name	Exposure to *	Latitude	Longitude	Site Status : Core Annual / Rotational/ Alternate/ Intensive Studies / Establishing Ref-Acc State / Suspended	Years Sampled															
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Athabasca River Mainstem	M0A	Reference Outside Nat Bit	54.7545	-113.3783	Core Annual*								X	X		X	X				4
	M0	Reference Outside Nat Bit	54.7265	-113.3006	Core Annual		X	X	X	X	X	X	X	X		X	X	X	X	X	13
	M1A	Reference Inside Nat Bit	56.6219	-111.6552	Core Annual*						X	X	X	X		X	X				6
	M1	Reference Inside Nat Bit	56.6416	-111.6191	suspended	XX	XX	XX	XX	XX	X										6
	M2A	Reference Inside Nat Bit	56.6927	-111.4626	Core Annual						X	X	X	X		X	X	X	X	X	9
	M2	Reference Inside Nat Bit	56.7431	-111.3895	suspended	XX	XX	XX	X	XX	X										6
	M3	Nat Bit & HIGH MSE	56.7938	-111.4042	Core Annual	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	X	14
	Northland	Nat Bit & HIGH MSE & MOD OSM	56.8792	-111.4328	Intensive Study													X	X	X	3
	M3B	Nat Bit & HIGH MSE & HIGH OSM	56.9473	-111.4427	Core Annual		XX	XX	XX	XX	X	X	X	X		X	X	X	X	X	13
	Sun-Up	Nat Bit & MOD MSE & HIGH OSM	56.9968	-111.4490	Intensive Study					X								X	X	X	4
	Sun-Dn	Nat Bit & MOD MSE & HIGH OSM	57.0438	-111.5037	Intensive Study					X								X	X	X	4
	M3C	Nat Bit & MOD MSE & HIGH OSM	57.0629	-111.5198	Intensive Study													X	X	X	3
	M4	Nat Bit & MOD MSE & HIGH OSM	57.0980	-111.5649	Core Annual	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	X	14
	M6	Nat Bit & MOD MSE & HIGH OSM	57.2020	-111.6104	Core Annual*	XX	XX	XX	XX	XX	X	X	X	X		X	X				11
	M7	Nat Bit & MOD MSE & HIGH OSM	57.3579	-111.6586	suspended		XX	XX	XX	XX			X								5
	M7B	Nat Bit & MOD MSE & HIGH OSM	57.4247	-111.6417	Intensive Study													X	X	X	3
	M7C	Nat Bit & MOD MSE & MOD OSM	57.5114	-111.5380	Core Annual*		XX	XX	XX	XX		X		X		X	X				8
	M8	Nat Bit & MOD MSE & MOD OSM	57.6570	-111.4259	Core Annual*	XX	XX	XX	XX	XX	X	X	X	X		X	X				11
	M9	Nat Bit & MOD MSE & MOD OSM	58.0666	-111.3681	Core Annual	XX	XX	XX	XX	XX	X	X	X	X		X	X	X	X	X	14
					∑	7	11	11	11	13	11	10	11	11	0	11	11	11	11	11	151

** paused during intensive work 2022-2025*

Table A1b. Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Site Status : Core Annual / Rotational/ Intensive Studies / Suspended	Years Sampled															
				2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Lower Athabasca River Tributaries	STEEPBANK RIVER	STBRIFF15	Rotational/ Alternate									x				x			2
		STBRIFF11	**Core Annual**	x		x	x	x		x	x	x		x	x	x	x		11
		STBRIFF13	**Core Annual**	x		x											x		3
		STBRIFF16	Rotational	x		x	x			x	x	x				x			7
		STBRIFF19	suspended	x			x		x		x								4
		STBRIFF17	Rotational	x		x	x			x		x				x			6
		STBRIFF10	**Core Annual**	x	x	x	x	x	x	x	x	x		x	x	x	x	x	14
		STBRIFF12	**Core Annual**							x				x	x	x	x		5
		STBRIFF09	**Core Annual**		x	x	x	x	x	x	x	x		x	x	x	x	x	13
		STBRIFF08	Rotational/ Alternate		x	x	x					x			x	x	x		7
		STBRIFF20	**Core Annual**			x	x	x		x		x			x	x	x	x	9
		STB RIFF 29	Intensive Study													x			1
		STBRIFF07A	Rotational/ Alternate				x		x							x			3
		STBRIFF07	**Core Annual**	x	x	x		x		x	x	x		x	x	x	x	x	12
		STBRIFF28	Intensive Study													x			1
		STBRIFF30	Rotational														x		1
		STBRIFF06 (XX = QC A/B)	Rotational/ Alternate		xx							x			x	x			4
		STBRIFF05 (XX = QC A/B)	**Core Annual**	xx	x	xx	x	x	x			x			x	x	x	x	11
		STBRIFF04	**Core Annual**	x		x	x	x		x		x				x	x		8
		STBRIFF04A	Rotational/ Alternate		x	x					x				x	x			5
		STB RIFF 27	Intensive Study													x	x		2
		STBRIFF03	**Core Annual**							x		x		x	x	x	x	x	7
		STB RIFF 26	Intensive Study													x			1
		STBRIFF21	**Core Annual**			x	x	x		x	x	x		x	x	x	x	x	11
		STB RIFF 25	Intensive Study													x	x		2
		STBRIFF02	**Core Annual**						x	x		x		x	x	x	x	x	8
		STBRIFF01	suspended	x	x	x	x	x											5
	∑#sites	27	**∑# sites sampled**	10	8	14	13	9	6	12	8	15	0	8	13	23	16	8	163
	MUSKEG AND JACKPINE RIVER	JPRIFFUP	suspended	x	x	x	x	x	x										6
		JPRIFFDN	suspended	x	x	x	x	x	x										6
		MUSRIFF03	**Core Annual**								x					x	x	x	4
		MUSRIFF02	Rotational/ Alternate					x		x				x	x				4
		MUSRIFF05	Establishing Ref/Acc State															x	1
		MUSRIFF01	**Core Annual**				x	x	x	x	x	x		x	x	x	x	x	11
		MUSRIFF04	Rotational/ Alternate									x		x					2
	∑#sites	7	**∑# sites sampled**	2	2	2	3	4	3	2	2	2	0	3	2	2	2	3	34
TAR RIVER ***NEW at request of SW TAC	TAR RIVER	TAR-RIFF 02	Establishing Ref/Acc State															x	1
		TAR-RIFF 01	Establishing Ref/Acc State															x	1
	∑#sites	2	**∑# sites sampled**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2

Table A1b (con't). Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Site Status : Core Annual / Rotational/ Intensive Studies / Suspended	Years Sampled															
				2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Lower Athabasca River Tributaries	MACKAY AND DOVER RIVERS	DUNRIFF01	suspended			x	x	x	x										4
		DOVRIFF04A	Rotational/ Alternate			x	x			x									3
		DOVRIFF04	Rotational/ Alternate		x														1
		DOVRIFF07	Rotational							x									1
		DOVRIFF03	Rotational/ Alternate						x					x				x	3
		DOVRIFF01	Rotational/ Alternate		x														1
		DOVRIFF02	Rotational/ Alternate		x	x	x	x		x									5
		DOVRIFF06	Rotational/ Alternate		x														1
		DOVRIFF05	Rotational/ Alternate		x	x	x	x	x								x	x	7
		DOVRIFF05A	Rotational/ Alternate							x		x		x	x				4
		MCKRIFF01	Rotational							x	x							x	3
		MCKRIFF07	Rotational	x	x	x													3
		MCKRIFF05	**Core Annual**	x	x	x	x	x	x	x	x	x			x	x			11
		MCKRIFF02	**Core Annual**	x	x	x	x			x	x			x	x	x	x	x	11
		MCKRIFF10	Intensive Study							x									1
		MCKRIFF03	**Core Annual**	x	x	x	x	x		x	x	x		x	x	x	x		12
		MCKRIFF03A	Rotational/ Alternate						x										1
		MCKRIFF11	Rotational/ Alternate							x									1
		MCKRIFF13	**Core Annual**												x			x	2
		MCKRIFF04	**Core Annual**		x	x	x	x			x	x		x	x		x	x	10
		MCKRIFF 18	Intensive Study															x	1
		MCKRIFF06	**Core Annual**		x	x	x	x	x	x		x		x	x	x	x		11
		MCKRIFF16	Rotational											x					1
		MCKRIFF08	**Core Annual**			x		x	x	x	x	x		x	x	x	x	x	11
		MCKRIFF03	**Core Annual**		x	x	x	x	x	x	x	x		x	x		x	x	12
		MCKRIFF 17	Intensive Study															x	1
		MCKRIFF15	Rotational	x	x	x	x		x	x								x	7
		MCKRIFF12	**Core Annual**	x	x	x	x	x	x	x	x	x		x	x	x	x	x	14
	∑ #sites	28	**∑ # sites sampled**	6	14	14	12	10	10	15	8	8	0	10	10	6	8	12	143

Table A1b (con't). Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Site Status : Core Annual / Rotational/ Intensive Studies / Suspended	Years Sampled															
				2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Lower Athbasaca River Tributaries	ELLS RIVER	ELLSRIFF17	Intensive Study														x		1
		ELLSRIFF15	Rotational/ Alternate							x	x								2
		ELLSRIFF09	**Core Annual**		x	x	x	x	x					x	x				7
		ELLSRIFF10	**Core Annual**			x	x								x		x		4
		ELLSRIFF06	**Core Annual**		x	x	x	x	x	x		x		x	x	x	x	x	12
		ELLS RIFF05A	Rotational/ Alternate					x				x					x		3
		ELLSRIFF05	**Core Annual**		x	x	x			x	x			x	x	x	x		9
		ELLSRIFF13	**Core Annual**		x				x	x	x	x		x	x		x	x	9
		ELLSRIFF11	**Core Annual**		x	x	x	x	x		x	x		x	x	x	x	x	12
		ELLSRIFF14	**Core Annual**						x	x				x			x		4
		ELLSRIFF16	Intensive Study														x		1
		ELLSRIFF02A	Rotational/ Alternate					x											1
		ELLSRIFF02	**Core Annual**	x	x	x	x		x	x	x	x		x	x	x	x	x	13
		ELLSRIFF01	Rotational/ Alternate	x		x				x							x		4
		ELLSRIFF01A	Rotational/ Alternate		x														1
		ELLSRIFF12	**Core Annual**					x	x			x		x	x	x	x	x	8
		ELLSRIFF04A	Rotational/ Alternate						x						x		x		3
		ELLSRIFF04	**Core Annual**		x	x	x	x		x	x	x		x				x	9
		ELLSRIFF07	**Core Annual**		x	x	x	x							x		x	x	7
		ELLSRIFF03A	**Core Annual**			x	x	x	x	x	x	x		x	x	x	x	x	12
		ELLSRIFF03	suspended	x															1
		JOSRIFF01	suspended	x	x	x	x	x											5
	∑#sites	22	**∑# sites sampled**	4	10	11	10	10	9	9	7	8	0	10	11	6	15	8	128

Table A1b (con't). Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Site Status : Core Annual / Rotational/ Intensive Studies / Suspended	Years Sampled															
				2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Lower Athabasca River Tributaries	FIREBAG RIVER	FIRTRIB04	Rotational				x	x	x			x							4
		FIRTRIB03	Rotational				x			x	x	x							4
		FIRTRIB05	suspended									x							1
		FIRTRIB02	Rotational			x	x	x	x									x	5
		FIRUPPER	**Core Annual**	x	x	x	x	x	x	x	x	x			x				10
		FIRUPPER01	**Core Annual**				x					x		x	x	x		x	6
		FIRUPPER02	Rotational/ Alternate							x									1
		FIRUPPER03	Rotational/ Alternate									x							1
		FIRMID03	**Core Annual**			x	x	x	x		x	x			x	x	x	x	10
		FIRMID06	**Core Annual**								x	x			x	x	x	x	6
		FIRMID09	Rotational/ Alternate									x							1
		FIRMID04	**Core Annual**				x				x			x	x			x	5
		FIRMID05	Rotational								x	x							2
		FIRMID	**Core Annual**		x	x	x	x	x	x	x	x		x	x	x	x	x	13
		FIRMID02	**Core Annual**			x	x	x	x		x	x			x	x		x	9
		FIRMID08	**Core Annual**								x	x				x			3
		FIRLOWER	**Core Annual**		x	x	x	x	x	x	x	x		x	x	x	x	x	13
		FIRMID07	Rotational								x							x	2
		FIRLOWER01	Rotational/ Alternate				x												1
		FIRLOWER02	Rotational				x	x			x	x		x					5
	∑#sites	20	**∑# sites sampled**	1	3	6	12	8	7	5	12	15	0	5	8	7	4	9	102

Table A1b (con't). Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for Lower Athabasca River Tributary benthic macroinvertebrate monitoring program that includes: Steepbank, MacKay, Ells, Muskeg, Firebag rivers and Birch Mountain region. *Exposure categories as in Culp et al., (2018).

Region	Major Tributary	Site Name	Site Status : Core Annual / Rotational/ Alternate/ Intensive Studies / Establishing Ref-Acc State / Suspended	Years Sampled															
				2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Birch Mountains	ALICE CREEK TRIB	JALICARIFF03	Rotational						x										1
		JALICARIFF04	Rotational						x										1
		JALICARIFF02	Rotational					x											1
		JALICARIFF01	Rotational					x	x						x			x	4
	ALICE CREEK	BIRTRIB07	Rotational				x	x	x	x						x		x	6
		BIRTRIB08	Rotational				x								x				2
		BIRTRIB06	Rotational				x												1
		BIRTRIB03	Rotational			x	x	x	x						x	x			6
		BIRTRIB02	Rotational		x	x	x		x	x					x			x	7
		BIRTRIB01	Rotational		x	x													2
	BIRCH TRIBUTARIES	BIRTRIB13	Rotational				x	x	x	x									4
		BIRTRIB14	Rotational				x												1
		BIRTRIB12	Rotational				x	x	x										3
		BIRTRIB04	Rotational				x		x	x									3
		BIRTRIB05	Rotational				x	x											2
	MCIVOR RIVER	BIRTRIB15	Rotational					x											1
		BIRTRIB16	Rotational					x	x	x	x	x		x	x				7
		BIRTRIB17	Rotational					x				x							2
		BIRTRIB19	Rotational						x			x							2
		BIRTRIB18	Rotational						x										1
		BIRTRIB21	Rotational						x			x		x					3
		BIRTRIB09	Rotational				x	x	x	x	x	x		x	x	x			9
		BIRTRIB22	Rotational									x		x					2
		BIRTRIB20	Rotational						x					x					2
		BIRTRIB10	Rotational				x	x	x	x	x	x		x		x			8
		BIRTRIB11	Rotational				x	x	x	x	x	x		x	x	x			9
	∑#sites	26	∑# sites sampled	0	2	3	13	13	17	8	4	8	0	7	7	5	0	3	90

Table A1c. Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for oil sands *in situ* regions including the Clearwater/ Christina, Horse and Hanginstone rivers, and the Cold Lake OSM Region.

Region	Major Tributary	Site Name	Latitude	Longitude	Site Status : Core Annual / Rotational/ Alternate/ Intensive Studies / Establishing Ref-Acc State / Suspended	Years Sampled															
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Σ
Clearwater/ Christina River Watershed	HIGH HILLS	HIGHHILLS	56.7516	-110.5062	suspended			x	x	x											3
	Christina River	CHRRIFF01	55.8784	-111.5134	Establishing Ref/Acc State								x			x	x	x	x		5
		CHRRIFF02	55.8082	-111.4049	Establishing Ref/Acc State								x			x	x	x	x	x	6
		CHRCBM01	55.8346	110.8685	Establishing Ref/Acc State												x	x	x	x	4
		CHRRIFF03	55.7001	111.4148	Establishing Ref/Acc State												x	x	x		3
		CHRRIFF42	55.7173	-111.2420	Establishing Ref/Acc State													x	x	x	3
		CHRRIFF04	55.7188	111.0587	Establishing Ref/Acc State													x	x	x	3
		CHRRIFF06	55.8525	-111.4578	Establishing Ref/Acc State													x	x	x	3
		CHRRIFF05A	55.8895	-111.5525	Establishing Ref/Acc State															x	1
		CHRRIFF05	55.8899	111.5578	Establishing Ref/Acc State													x	x		2
	Christina River Tributary	CHRTRIB01	55.6997	-111.4160	Establishing Ref/Acc State									x				x	x	x	4
		CHRTRIB02	55.7085	-111.4811	Establishing Ref/Acc State									x			x	x	x	x	5
	Cottonwood Creek	COTRIFF01	56.1634	-110.9932	Establishing Ref/Acc State								x	x		x	x				4
		COTRIFF02	56.1486	-110.9584	Establishing Ref/Acc State								x				x	x			3
		COTRIFF03	56.1382	-110.9286	Establishing Ref/Acc State								x	x		x					3
		COTRIFF04	56.1393	-110.8960	Establishing Ref/Acc State												x	x			2
	Gregoire River	GRERIFF01	56.4750	-110.8448	Establishing Ref/Acc State								x	x		x	x	x	x	x	7
		GRERIFF02	56.3762	-110.9826	Establishing Ref/Acc State								x	x		x	x	x	x	x	7
		GRERIFF03	56.3672	-110.8673	Establishing Ref/Acc State								x	x		x	x	x	x	x	7
		GRERIFF04	56.4260	-110.8198	Establishing Ref/Acc State								x	x		x	x	x	x	x	7
		GRERIFF05/ GREGRIFF 5A	56.3527	-110.7771	Establishing Ref/Acc State													x	x	x	3
		GRERIFF06	56.3977	110.8436	Establishing Ref/Acc State													"	"	"	3
		GRERIFF07/ GREGRIFF 7A	56.4133	-111.0707	Establishing Ref/Acc State													x			1
	Kettle River	KETRIFF01	56.0139	-111.0497	Establishing Ref/Acc State									x		x	x				3
		KETRIFF02	56.0440	-111.1111	Establishing Ref/Acc State									x							1
		KETRIFF02A	56.0451	111.1108	Establishing Ref/Acc State												x	x			2
		KETRIFF03	56.0144	111.0517	Establishing Ref/Acc State													x			1
		KETCBM 01/01A	55.9867	-110.9491	Establishing Ref/Acc State													#	x	x	3
		KETCBM02	55.9924	-110.8209	Establishing Ref/Acc State														x	x	2
		KETCBM04	55.9784	-110.7686	Establishing Ref/Acc State														x	x	2
	Meadow Creek	MEDRIFF01	56.2728	-110.8705	Establishing Ref/Acc State								x	x		x	x				4
		MEDRIFF01A	56.2731	110.8690	Establishing Ref/Acc State													x	x	x	3
		MEDRIFF02	56.2156	-111.0560	Establishing Ref/Acc State								x	x		x					3
		MEDRIFF03	56.2195	-110.9577	Establishing Ref/Acc State								x			x	x	x	x	x	6
	Pony Creek	PONYRIFF01	55.8613	-111.0078	Establishing Ref/Acc State									x		x	x				3
		PONYRIFF02	55.8699	-110.9176	Establishing Ref/Acc State									x		x	x				3
		PONYRIFF03	55.6714	111.0978	Establishing Ref/Acc State												x				1
	Waddell Creek	WADRIFF01	55.8100	-111.0796	Establishing Ref/Acc State									x		x	x	x	x		5
		WADRIFF02	55.8519	-111.1716	Establishing Ref/Acc State									x		x	x	x			4
	Jackfish River	JACCBM01	55.6714	111.0978	Establishing Ref/Acc State												x	x	x	x	4
		JACRIFF01	55.7088	-111.0853	Establishing Ref/Acc State													x	x	x	3
	May River	MAYCBM01	55 50074	-111 5208.8	Establishing Ref/Acc State													x	x	x	3
		MAYRIFF37	55.6673	-111.3784	Establishing Ref/Acc State													x	x	x	3
		MAYRIFF35	55.6731	-111.3615	Establishing Ref/Acc State													x	x	x	3
	Surmont Creek	SURWLMN01	56.3221	-111.2138	Establishing Ref/Acc State														x	x	2
		SURWLMN02	56.3951	-111.1515	Establishing Ref/Acc State														x	x	2
	∑ #sites	45				0	0	1	1	1	0	0	12	16	0	16	22	31	29	24	155

Table A1c (con't). Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for oil sands *in situ* regions including the Clearwater/ Christina, Horse and Hanginstone rivers, and the Cold Lake OSM Region.

Region	Major Tributary	Site Name	Latitude	Longitude	Site Status : Establishing Reference and Accumulated State / Suspended	Years Sampled															
						2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Additional InSitu/ SAGD Streams near Fort McMurray	HORSE RIVER	HRSRIFF03	56.5219	-111.8413	Establishing Ref/Acc State								x							x	2
		HRSRIFF04	56.5212	-111.8335	Establishing Ref/Acc State								x								1
		HRSRIFF05	56.5416	-111.6701	Establishing Ref/Acc State									x						x	2
		HRSRIFF06	56.5553	-111.6195	Establishing Ref/Acc State									x				x			2
		HRSRIFF07	56.6311	-111.5328	Establishing Ref/Acc State									x			x		x	x	4
		HRSRIFF02	56.6740	-111.4213	Establishing Ref/Acc State						x	x	x	x			x		x	x	7
		HRSRIFF01	56.7031	-111.3937	Establishing Ref/Acc State						x	x	x	x			x	x	x		7
	∑ #sites	7				0	0	0	0	0	2	2	4	5	0	0	3	2	3	4	25
	HANGINGSTONE RIVER	HNGRIFF03	56.4037	-111.3851	Establishing Ref/Acc State								x	x		x	x	x	x	x	7
		HNGRIFF04	56.4703	-111.4095	Establishing Ref/Acc State								x			x	x	x	x	x	6
		HNGRIFF02	56.6497	-111.3566	Establishing Ref/Acc State						x	x		x			x	x			5
		HNGRIFF01	56.6868	-111.3678	Establishing Ref/Acc State						x	x	x	x				x	x	x	7
		HNGRIFF05	56.6915	-111.3721	Establishing Ref/Acc State									x			x				2
		HNGRIFF06	56.4963	-111.3931	Establishing Ref/Acc State												x		x	x	3
		HNGRIFF07	56.4411	-111.4076	Establishing Ref/Acc State												x		x	x	3
		HNGRIFF07A	56.4429	-111.4109	Establishing Ref/Acc State													x			1
		HNGRIFF08	56.4781	-111.4107	Establishing Ref/Acc State												x				1
	∑ #sites	9				0	0	0	0	0	2	2	3	4	0	2	7	5	5	5	35
COLD LAKE OIL SANDS AREA		MEDCLFN01	54.6305	-110.2089	Establishing Ref/Acc State													x	x	x	3
		JFCCLFN01	54.6347	-110.5716	Establishing Ref/Acc State													x	x	x	3
		MARCLFN01	54.6965	-110.3786	Establishing Ref/Acc State													x	x	x	3
		MARCLFN02	54.5841	-110.3277	Establishing Ref/Acc State														x		1
		MARCLFN04	54.5471	-110.3595	Establishing Ref/Acc State														x		1
		MARCLFN05	54.5200	-110.3198	Establishing Ref/Acc State														x		1
		MEDCLFN02	54.6074	-110.1941	Establishing Ref/Acc State													x	x	x	3
		WOLCLFN01	54.8938	-110.4640	Establishing Ref/Acc State															x	1
		WOLCLFN02	54.8462	-110.5661	Establishing Ref/Acc State															x	1
		WOLCLFN03	54.7336	-110.9619	Establishing Ref/Acc State															x	1
	∑ #sites	10				0	0	0	0	0	0	0	0	0	0	0	0	4	7	7	18

Table A1d. Oil Sands Monitoring Program 2011-2025: Detailed annual sampling summary for the Peace River Oil Sands Region.

Region	Site Name	Latitude	Longitude	Site Status : Core Annual / Rotational/ Alternate/ Intensive Studies / Establishing Ref-Acc State / Suspended	Years Sampled															
					2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	∑
Peace River Oil Sands Area	LOON01	57.1164	-115.0966	Establishing Ref/Acc State									x							1
	LOON02	57.0504	-115.0941	Establishing Ref/Acc State									x							1
	MUD01	57.5252	-115.4974	Establishing Ref/Acc State									x							1
	WAB18	57.6556	-115.3983	Establishing Ref/Acc State									x							1
	WAB21B	57.5696	-115.4120	Establishing Ref/Acc State									x							1
	WAB22D	57.5108	-115.5016	Establishing Ref/Acc State									x							1
	WAB23B	57.3244	-115.2499	Establishing Ref/Acc State									x							1
	WAB30B	57.0938	-114.8950	Establishing Ref/Acc State									x							1
	WAB32	57.0982	-114.6278	Establishing Ref/Acc State									x							1
	WAB44B	56.5929	-113.6157	Establishing Ref/Acc State									x							1
	WAB45B	56.5255	-113.6710	Establishing Ref/Acc State									x							1
	WAB48B	56.4425	-113.7162	Establishing Ref/Acc State									x							1
	LGERIFF01	56.8441	-113.8175	Establishing Ref/Acc State						x										1
	LGERIFF02	56.8736	-113.8386	Establishing Ref/Acc State						x										1
	LGERIFF03	56.9333	-113.9151	Establishing Ref/Acc State						x										1
	PEATRIB01	57.7907	-116.7902	Establishing Ref/Acc State							x									1
	PEATRIB02	57.6888	-116.7863	Establishing Ref/Acc State							x									1
	PEATRIB03	57.6535	-116.8355	Establishing Ref/Acc State							x									1
	WABTRIB01	56.9230	-114.3586	Establishing Ref/Acc State						x										1
				∑	0	0	0	0	0	4	3	0	12	0	0	0	0	0	0	19

Appendix B

Representative Examples of Presentations provided to the OSM office and Surface Water TAC members in 2020 and 2023. Other presentations listed in the report are available upon request. See Glozier et.al, 2025 for original Appendix B for presentations 1-4.

1) GLOZIER*, N.E., R.B. BRUA*, A. RITCEY, J. HANISCH*, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrates – Thoughts on limits of change. Surface Water Technical Advisory Committee Meeting, 22-24 August 2023, Calgary, Alberta. * Co-presenters

2) GLOZIER*, N.E., R.B. BRUA*, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2023. Oil Sands Monitoring: Benthic macroinvertebrate Communities 2012 to 2023. Water Technical Advisory Committee Meeting, 24-25 July 2023, Calgary, Alberta. * Co-presenters

3) BRUA*, R.B., J.M. CULP, & N.E. GLOZIER. 2020. Aquatic ecosystem health monitoring: Benthic macroinvertebrates. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta. * Presenter

4) Glozier*, N.E. A. Ritcey, K. Hynes and J. Hanisch 2020. Aquatic Ecosystem Health Monitoring – Benthic Macroinvertebrates. OSM Area – FMM Tributaries; SAGD Areas, South of FMM, Peace River and Cold Lake. Oil Sands Monitoring Program Aquatic Ecosystem Health Monitoring Workplan Workshop, 8-9 January 2020, Calgary, Alberta. * Presenter

5) GLOZIER*, N.E., R.B. BRUA, A. RITCEY, L. LEVESQUE, J. HANISCH, & K. HYNES. 2025. Biomonitoring OSM program design and adaptation in the Tributaries. Invited presentation at 2025 COSIA Water, Tailings and Land Science Workshop October 21, 2025 (Virtual). * Presenter

Biomonitoring OSM program design and adaptation in the Tributaries

Presenter: Nancy E. Glozier (ECCC)

Study Team Members:
ECCC – Robert Brua, Allison Ritcey, Lucie Levesque,
AEPA - Justin Hanish, Kristin Hynes

October 21, 2025

2025 COSIA Water, Tailings and Land Science Workshop

OIL SANDS MONITORING PROGRAM

Canada

Environment and Climate Change Canada | Environnement et Changement climatique Canada

Alberta Environment and Protected Areas

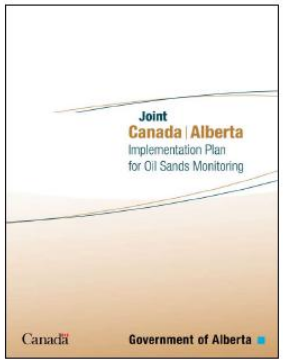
Benthic Invertebrate (BMI) OSM program design and adaptation for Lower Athabasca River and Tributaries

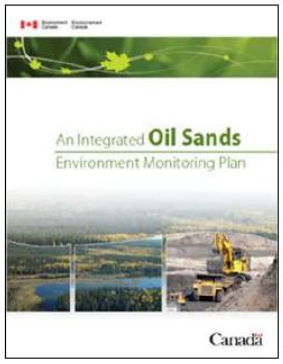
Outline/ Objectives

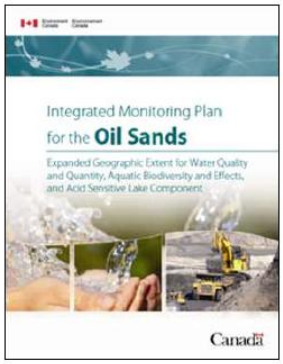
1. **Review BMI monitoring design in Lower Athabasca River (LAR)**
   - **Pre and post JOSM**
   - **Adaptations through OSM**
   - **Current program**
2. **Provide examples of scientific data evaluation during adaption**
   - **Steepbank River**

Classification: Protected A

Background: Core BMI Monitoring – Why?







The Governments of Canada and Alberta developed a detailed, multi-media (i.e. air, water and terrestrial habitat-focused) Oil Sands monitoring program which addressed impacts within the mining area, and in downstream habitats of the Peace-Athabasca Delta and Slave River.

Box 1: Examples of key questions to be answered by the monitoring program:

- ✓ What is the current state of the water quality of the Athabasca River basin?
- ✓ Which contaminants and levels are entering the Athabasca River directly or indirectly from oil sands operations?
- ✓ What is the distribution of contaminants in the aquatic ecosystem with particular reference to water and sediments?
- ✓ Can contaminant types and loads be attributed to specific sources?
- ✓ Are toxic substances such as mercury, naphthenic acids, PACs increasing or decreasing and what is their rate of change?
- ✓ Are the substances added to the rivers by natural and man-made discharges likely to cause deterioration of the water quality? What is the relative importance of both inputs?
- ✓ What are the cumulative effects of land use alterations and man-made discharges on the water and aquatic environment?
- ✓ Do current contaminant loads or concentrations pose threats to human health or subsistence?

Classification: Protected A

Background: Core BMI Monitoring – Why?

Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring in 2012 was developed to provide scientifically robust monitoring of aerial, freshwater and terrestrial environments

Objectives for Aquatic Ecosystem Health:

1. What is the current status?
2. Are changes in indicators occurring in the oil sand region?
3. Is there evidence of cumulative effects on biota?
4. Do predictive relationships exist that link drivers to biotic responses?

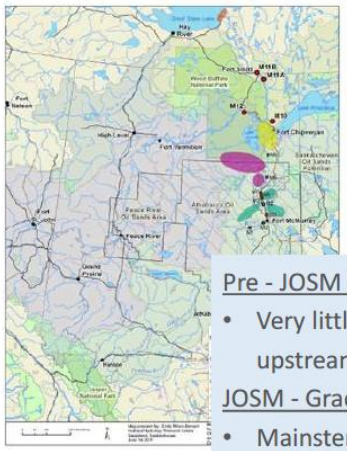
The Govern
air, water a
addressed i
Peace-Athabasca Delta and Slave River.

Box 1: Examples of key questions to be answered by the monitoring program:

concentrations pose threats to human health or subsistence?

Classification: Protected A

Background: Core BMI Monitoring – Why/ Where?









Pre - JOSM Sampling

- Very little on Athabasca River; AEOSERP/RAMP – upstream downstream on tributaries

JOSM - Gradient Designs Integrated with WQ & Fish

- Mainstem Lower Athabasca River
- Major Tributaries including Steepbank, MacKay, Muskeg, Ells, Firebag
- Birch Hills area predevelopment
- Peace River & Cold Lake OS Areas to be phase in

Classification: Protected A

Background: Core BMI Monitoring – What/How?

Canadian Aquatic Biomonitoring Network (CABIN) protocol for wadeable streams with additional stressor measures for habitat/chemistry samples



Detailed Methods Studies – mesh size, sampler type, habitat (sand/cobble)

Sampling approach & media consistent for all areas

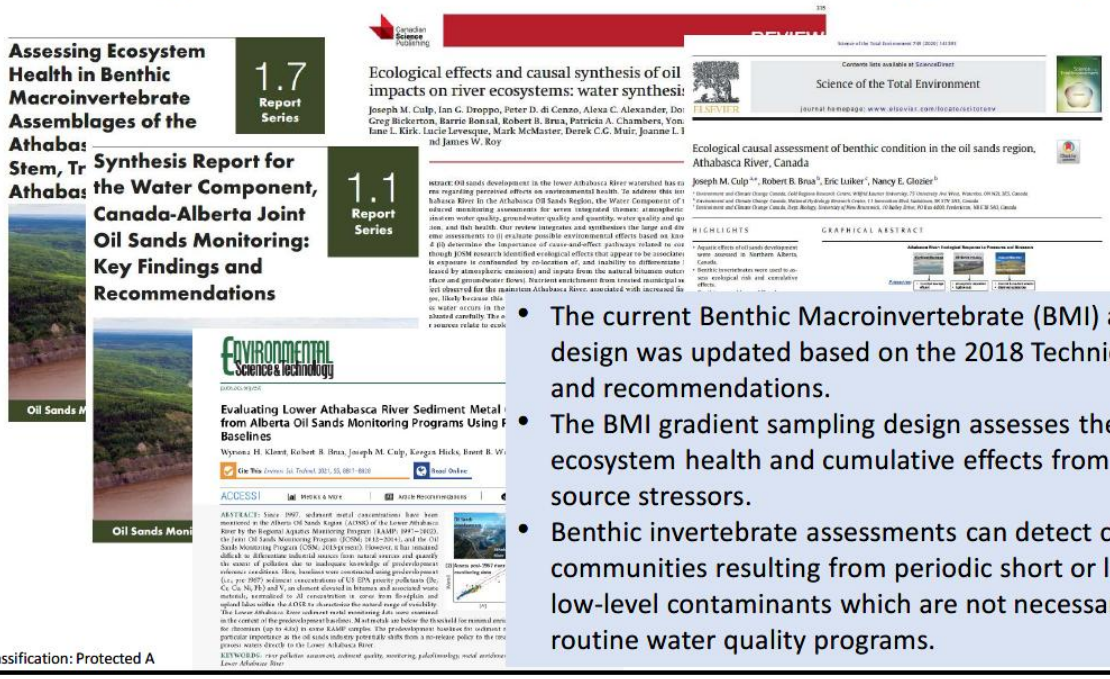
- WQ – Major Ions, Nutrients, PACs, Dissolved & Total & Metals, Physicals (pH, conductivity, turbidity)
- Sediment Quality – Metals, PACs, Mercury
- Passive Sampling – Time-integrated SPMD samples for dissolved Polyaromatic Compounds (PACs)
- Physical Habitat – substrate, velocity, depth, bankful +
- Periphyton & Seston biomass - Chla

Standard Operating Procedures published including WQ field, SPMD field, SPMD data management,, Enhance Benthic protocols. Available online: Dataset - Oil Sands Monitoring; Standard Operating Procedures for Benthic Invertebrate Monitoring in Wadeable Streams of the Athabasca Oil Sands Region; additions to the national CABIN protocol - Datasets - Oil Sands Monitoring (alberta.ca); Benthic Macroinvertebrate Biomonitoring Program: Mainstem Athabasca River - Federal Open Science Repository of Canada



Classification: Protected A

Background: Core BMI Monitoring: Adaptation



- The current Benthic Macroinvertebrate (BMI) adaptive monitoring design was updated based on the 2018 Technical Report findings and recommendations.
- The BMI gradient sampling design assesses the overall aquatic ecosystem health and cumulative effects from point and non-point source stressors.
- Benthic invertebrate assessments can detect changes in the BMI communities resulting from periodic short or long-term exposure to low-level contaminants which are not necessarily detected through routine water quality programs.

Classification: Protected A

Current State: Key JOSM Questions & Results



Current State?

Change?

Cumulative Effects?

Predictive Relationships?

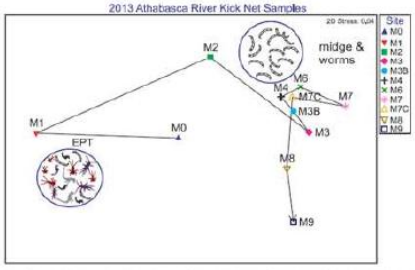


Figure 17. Path ordination diagram (nonmetric multidimensional scaling) of the averaged benthic macroinvertebrate community composition for 11 sites collected in September 2013 along the Lower Athabasca River. Composition changes from taxa associated with reference sites (EPT; Ephemeroptera, Plecoptera, Trichoptera) to pollution tolerant forms in mid-reaches in the area of development. Downstream sites considerably downstream of the development shifted back towards reference communities upstream of the disturbance.

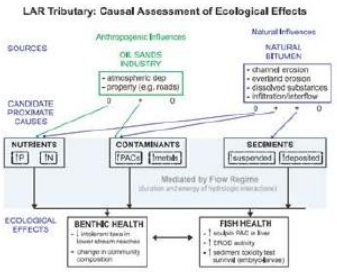


Figure 21. Lower Athabasca Tributaries: causal assessment of observed ecological effects showing linkages between sources of effects (industry and natural bitumen), candidate proximate causes (nutrient enrichment, contaminant exposure via surface water and sediments, habitat change from suspended and deposited sediment) and groundwater input (including contaminants).

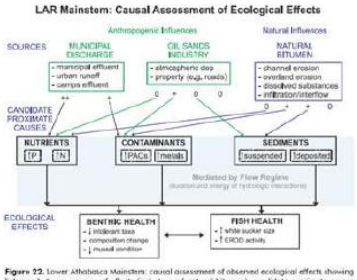
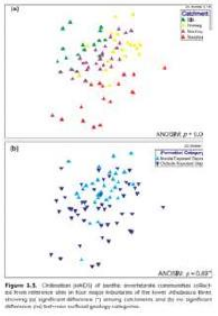


Figure 22. Lower Athabasca Mainstem: causal assessment of observed ecological effects showing linkages between sources of effects (industry and natural bitumen), candidate proximate causes (nutrient enrichment, contaminant exposure via surface water and sediments, habitat change from suspended and deposited sediment) and groundwater inputs (including contaminants).



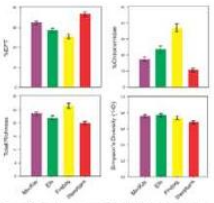


Figure 3.6. Key benthic metrics (EPT SR) calculated for four major tributaries of the Athabasca River. Data from all sampling years were pooled per catchment.

Recommendations: additional reference sites, further work for causal linkages and metrics, investigate co-occurring nutrient/contaminant gradients in mainstem, and natural and anthropogenic gradients in the tributaries.

Classification: Protected A

Core BMI Study Design & Indicators 2018+

Study Design

1) Two Reference types: Outside & Inside Naturally Exposed OS geology
2) Multiple Test Areas – inside OS geology with increasing gradient of activities (OS & MSE, disturbance)

	Reference Site (Outside Deposit)	Reference Site (Inside Deposit)	Test Site
Natural Exposure to Bitumen?	N	Y	Y
Is the site within the oil sands open pit mining footprint, and/or does the site have > 10% active lease AND > 1% land disturbance in the upstream catchment?	N	N	Y & test categories based on increasing exposure gradients

Indicators

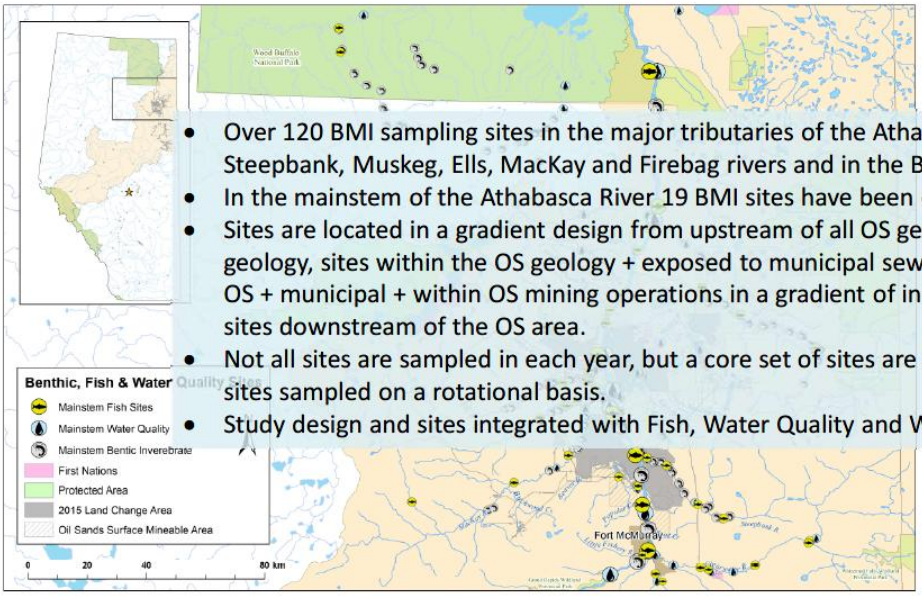
1) Change in Benthic Macroinvertebrate Assemblage
   a) nMDS Ordination
   b) Bray-Curtis (B-C) Index
2) Change in Benthic Macroinvertebrate Structure
   a) Family Richness
   b) Total Abundance
   c) %Trichoptera
3) Evaluating numerous potential endpoints
   a) Functional endpoints (FFG, decomposition, etc.)

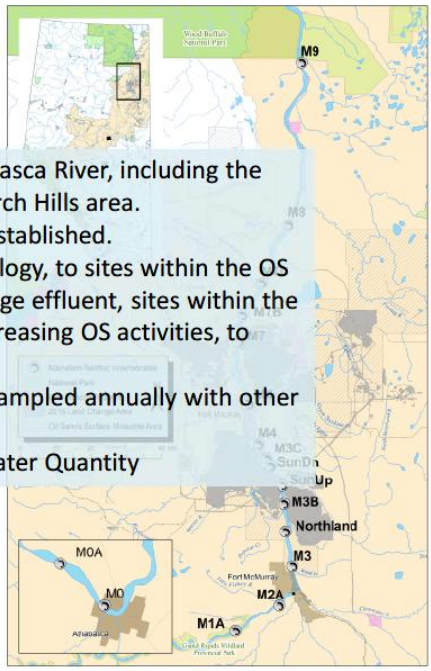




Classification: Protected A

Core BMI Monitoring Sites Where 2018+





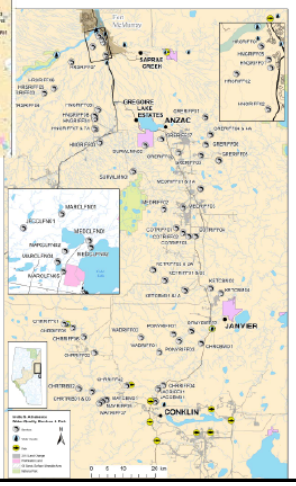
- Over 120 BMI sampling sites in the major tributaries of the Athabasca River, including the Steepbank, Muskeg, Ells, MacKay and Firebag rivers and in the Birch Hills area.
- In the mainstem of the Athabasca River 19 BMI sites have been established.
- Sites are located in a gradient design from upstream of all OS geology, to sites within the OS geology, sites within the OS geology + exposed to municipal sewage effluent, sites within the OS + municipal + within OS mining operations in a gradient of increasing OS activities, to sites downstream of the OS area.
- Not all sites are sampled in each year, but a core set of sites are sampled annually with other sites sampled on a rotational basis.
- Study design and sites integrated with Fish, Water Quality and Water Quantity

Classification: Protected A

Core BMI Monitoring Sites Where 2018+



In Situ Christina, Horse, Hangingstone & Cold Lake OS Areas



		Sampling Summary: 2011-2023					Exposure Categories Present					
	Sampling Area	Total # Sites	Year of First Sampling	# Years Sampled	Total # Samples	Avg. # Samples / Year (excluding 2011 & 2020)	Reference Outside Nat Bit	Reference Inside Nat Bit	Inside Natural Bit + MSE	Inside Natural Bit + MSE + OS Dev Activities	Inside Natural Bit + OS Dev Activities	Inside Natural Bit + Reduced OS Dev Activities (i.e., Recovery)
Athabasca River Mainstem	Lower Athabasca River Gravel Site	19	2011	12	645	55	√	√	√	√	---	√
	Lower Athabasca River Sand Sites	10	2011	5	230	50	---	√	√	√	---	√
Athabasca River & PAD Tributaries	Steepbank River	26	2011	12	142	12	√	---	---	---	√	---
	MacKay /Dover River	24	2011	12	123	11	√	√	---	---	√	---
	Muskeg and JackPine	6	2011	12	29	3	---	√	---	---	√	---
	Ells River	18	2011	12	105	9	√	√	---	---	√	---
	Firebag River	20	2011	12	89	8	√	√	---	---	√	---
	Birch Mountains	26	2012	11	87	8	√	---	---	---	---	---
In Situ/SAGD Areas	Horse River	7	2016	7	18	6	na - not yet classified					
	Hangingstone River	9	2016	7	25	4						
	Christina River Watershed	41	2018	5	100	20						
	Cold Lake Oil Sands Area	4	2023	1	4	4						
	Peace River Oil Sands Area	19	2016	3	19	6						
	Total	229	na	na	1616	196						

	Total number of samples by Tributary and Exposure Category									
	Birch Mtns	Dover	MacKay	Ells	Firebag	Steepbank	Musk/Jack	Total	%	
Reference - Outside Exposed Deposit	87	9	38	22	38	43	---	237	41%	52%
Reference - Inside Exposed Deposit	---	18	---	17	22	---	6	63	11%	
Inside Exp Dep + OSM Test Group 1	---	---	21	25	29	21	23	119	21%	48%
Inside Exp Dep + OSM Test Group 2	---	---	37	20	---	22	---	79	14%	
Inside Exp Dep + OSM Test Group 3	---	---	---	21	---	34	---	55	10%	
Inside Exp Dep + OSM Test Group 4	---	---	---	---	---	22	---	22	4%	
Total number of samples	87	27	96	105	89	142	29	575	100%	

Classification: Protected A

BMI OSM program design and adaptation for Lower Athabasca River

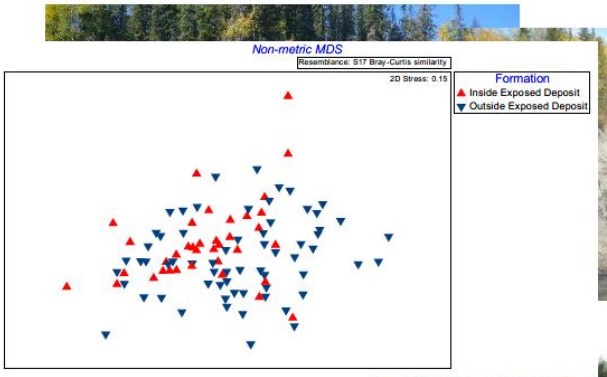
Outline/ Objectives

1. **Review BMI monitoring design in Lower Athabasca River (LAR)**
   - **Pre and post JOSM**
   - **Adaptations through OSM**
   - **Current program**
2. **Provide examples of scientific data evaluation during adaption**
   - **Steepbank River BMI Assessment**

Classification: Protected A

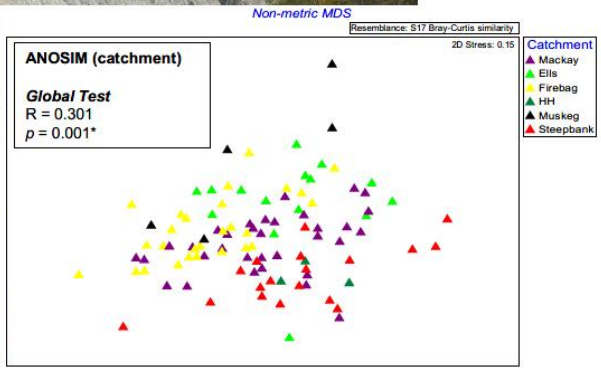
Current State: Tributaries 2011-2018

- Two Reference Types - Similar BMI communities
- Reference Areas among Major Tributaries – different BMI communities



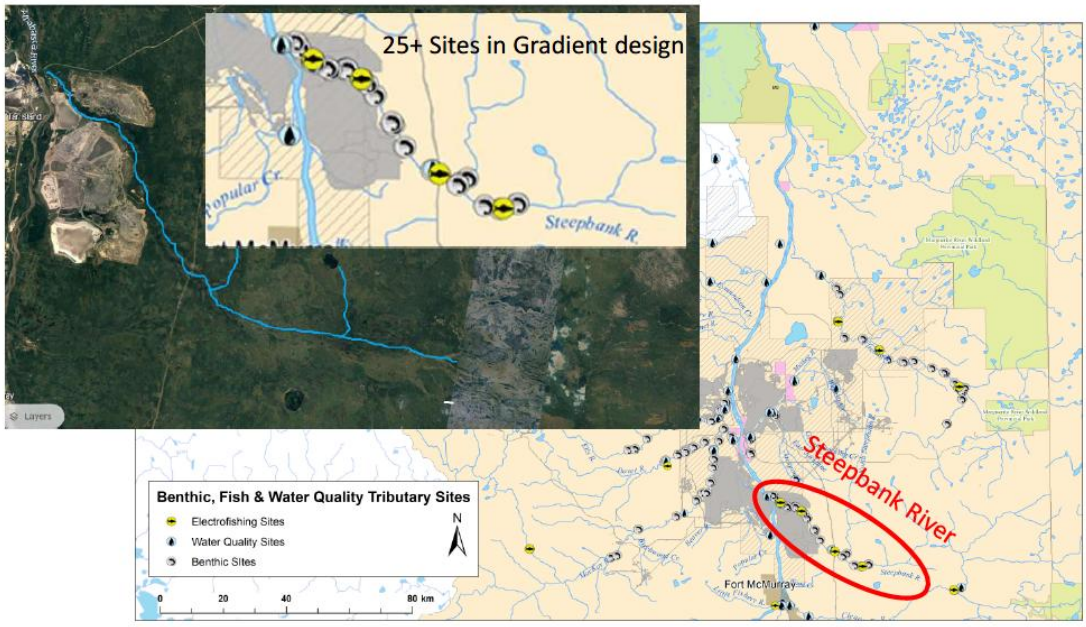






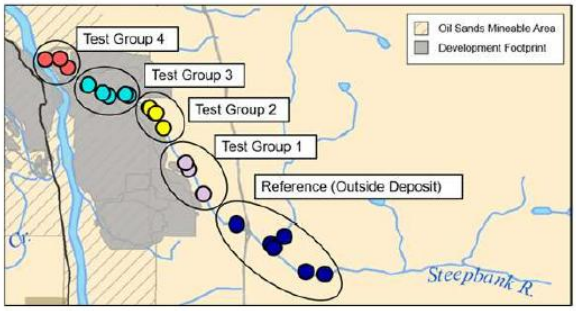
Classification: Protected A

Current State: Tributaries 2011-2018



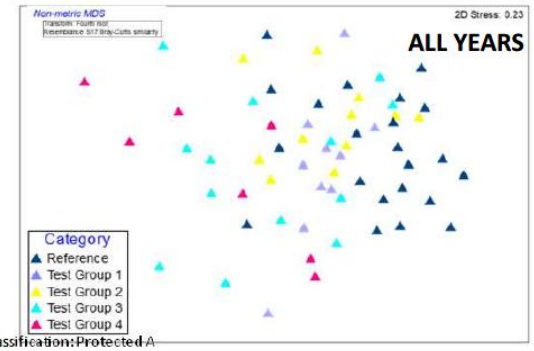
Classification: Protected A

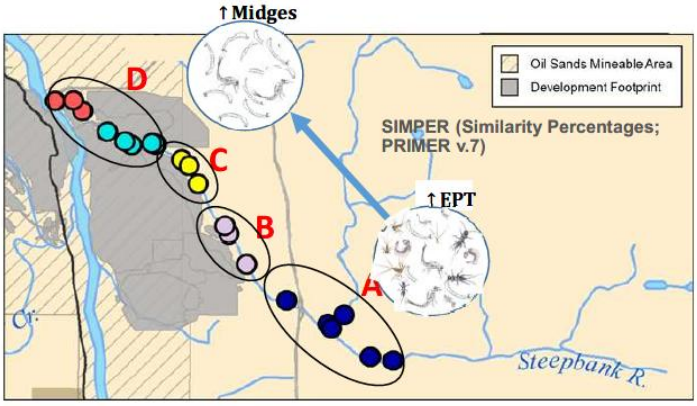
Current State: Steepbank River 2011-2018



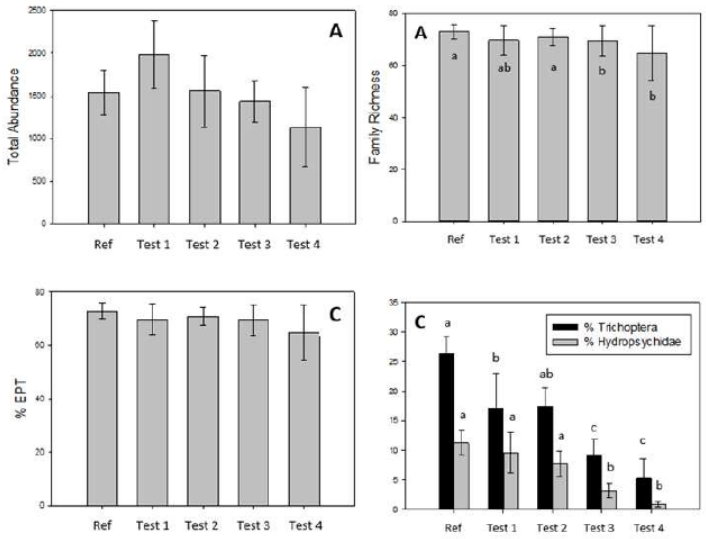
PERMANOVA (Permutational ANOVA; PRIMER v.7)

	PERMANOVA p values				
	Ref	Test 1	Test 2	Test 3	Test 4
Ref		0.001*	0.001*	0.001*	0.001*
Test 1			0.08*	0.043*	0.001*
Test 2				0.043*	0.001*
Test 3					0.231
Test 4					





Current State: Steepbank River - Metrics



Major Tributaries in the Oil Sands Area

- BMI communities in tributaries have many pollution sensitive taxa, such as mayflies, stoneflies and caddisflies (i.e., Ephemeroptera, Plecoptera and Trichoptera (EPT));
- BMI communities in areas with increased human disturbance from Oil Sands surface mining activities are different from reference sites and have an increased number of pollution tolerant taxa, such as worms and midges;
- Family Richness (# of taxa) show a decreasing pattern from upper reference areas to lower areas with OS surface mining activities.
- The proportion of caddisflies & Hydropsychidae showed a substantial decreasing pattern from upper reference areas to lower areas.
- Sites in Oil sands development areas tended to have higher concentrations of dissolved metals, sediment PACs, and major ions (e.g., Chloride) compared to Reference areas.

Current State: Steepbank River – Environmental parameters

BIOENV multivariate routine in Primer-e – ***assesses correlations between invertebrate community patterns in nMDS and patterns in environmental parameters for all samples. Assessments are not dependent on site categories.***

Environmental parameters assessed (n=125, initially > 250):

1. Water Quality - **79** parameters including nutrients, major ions, dissolved and total metals, Polycyclic Aromatic Compounds (PACs)s, Physicals
2. Sediment Quality - **32** parameters including metals, PACs and Hg.
3. Habitat characteristics – **10** measurements including velocity, depth, substrate, bankfull width etc.,
4. Biological drivers – **4** parameters including % Periphyton coverage and Biomass (Chla), Canopy Coverage and streamside vegetation.

Assessment steps:

1. QA/QC and review of all data to meet criteria (% detections, complete data set for all samples, correlations among parameters for redundancy, differences in types of stressors)
2. Independent BIOENVs were run on 13 stressor assessment groups (nutrients, metals, habitat, etc.,) to determine the drivers within those groups with the **highest correlation values.**
3. Selected those parameters that had **significant correlations with the highest R values** to input to a final **overarching BIOENV analysis with 18 final parameters.**

Classification: Protected A

Current State: Steepbank River

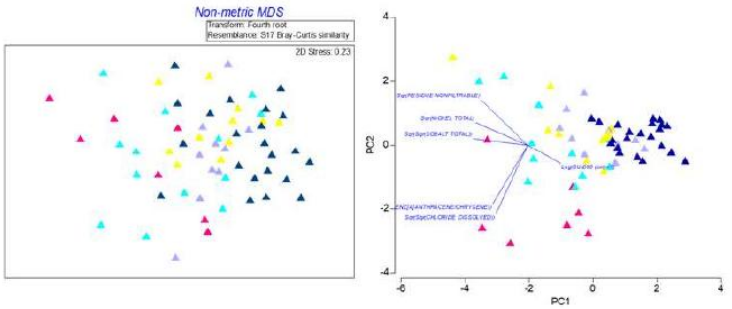
FINAL BIO-ENV

Channel measurements
Substrate (D50)
Bankfull width
% Canopy cover (avg)
Periphyton biomass (Chl-a g/m²)

Sediment Quaity
C2_benz(a)anthracene/chrysene
C3_benz(a)anthracene/chrysene
Total PACs

Water Quality
Residue (NFR)
Chloride dissolved
Nickel total
Cobalt total
Arsenic dissolved
Vanadium total
Antimony dissolved
Copper dissolved
Selenium dissolved
Sulphate dissolved
Phenanthrene

Parameters in red were the most highly correlated with invertebrate assemblage patterns
BIO-ENV R = 0.568



Classification: Protected A

Current State: Steepbank River

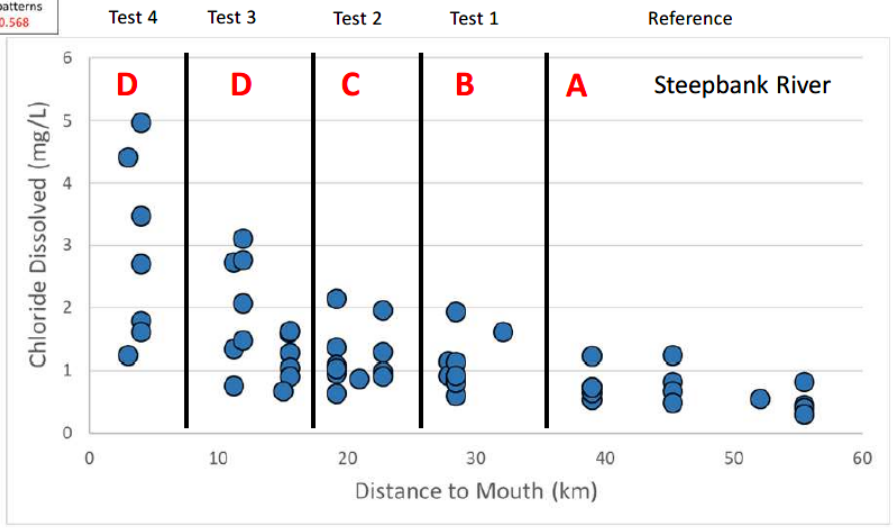
FINAL BIO-ENV

Channel measurements
Substrate (D50)
Bankfull width
% Canopy cover (avg)
Periphyton biomass (Chl-a g/m²)

Sediment Quaity
C2_benz(a)anthracene/chrysene
C3_benz(a)anthracene/chrysene
Total PACs

Water Quality
Residue (NFR)
Chloride dissolved
Nickel total
Cobalt total
Arsenic dissolved
Vanadium total
Antimony dissolved
Copper dissolved
Selenium dissolved
Sulphate dissolved
Phenanthrene

Parameters in red were the most highly correlated with invertebrate assemblage patterns
BIO-ENV R = 0.568



Current State: Steepbank River

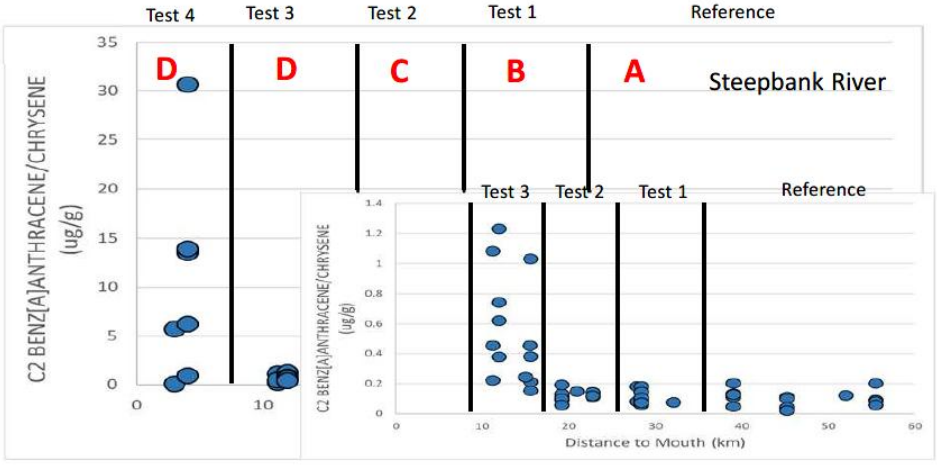
FINAL BIO-ENV

Channel measurements
Substrate (D50)
Bankfull width
% Canopy cover (avg)
Periphyton biomass (Chl-a g/m²)

Sediment Quaity
C2_benz(a)anthracene/chrysene
C3_benz(a)anthracene/chrysene
Total PACs

Water Quality
Residue (NFR)
Chloride dissolved
Nickel total
Cobalt total
Arsenic dissolved
Vanadium total
Antimony dissolved
Copper dissolved
Selenium dissolved
Sulphate dissolved
Phenanthrene

Parameters in red were the most highly correlated with invertebrate assemblage patterns
BIO-ENV R = 0.568



Classification: Protected A

Current State: BMI in Oils Sands Area

Are changes in indicators (invertebrates) occurring in the oil sands region?
Yes, there are confirmed changes in invertebrate assemblages in the LAR and Tributaries from upstream reference sites to downstream test sites and with some metrics.

Are environmental drivers linked to biotic responses?
Yes, chemical and physical habitat parameters are correlated with invertebrate assemblage patterns.

Next Steps

1. Intensive study in areas of greatest change in the LAR and Tributaries 2023-2025
2. Further assess correlates/ drivers and investigate if drivers identified are linked to oil sands activities?

Classification: Protected A

Thank You, Questions?

The Authors acknowledge the support of the Oil Sands Monitoring program

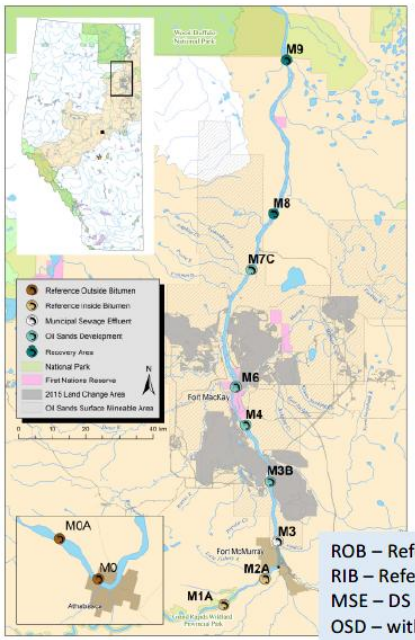


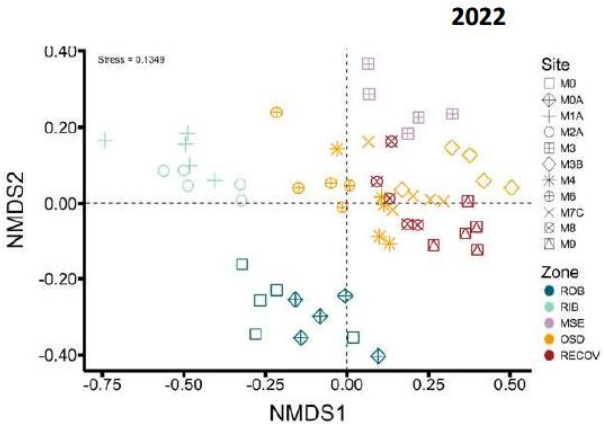
Classification: Protected A

APPENDIX SLIDES

Classification: Protected A

Current State: Mainstem Athabasca River





One-way ANOSIM		R
Zone	**p < 0.001**	R = 0.753

Pairwise ANOSIMs		
ROB vs RIB	**p < 0.001**	**R = 0.940**
ROB vs MSE	**p < 0.001**	**R = 0.948**
ROB vs OSD	**p < 0.001**	**R = 0.801**
ROB vs RECOV	**p < 0.001**	**R = 0.951**
RIB vs MSE	**p < 0.001**	**R = 1.000**
RIB vs OSD	**p < 0.001**	**R = 0.891**
RIB vs RECOV	**p < 0.001**	**R = 1.000**
MSE vs OSD	**p < 0.001**	**R = 0.536**
MSE vs RECOV	**p < 0.001**	**R = 0.765**
OSD vs RECOV	**p = 0.016**	**R = 0.186**

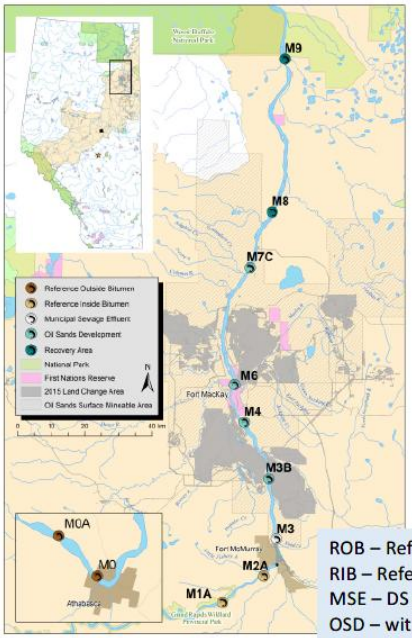
NMDS1 – related to increasing nutrients

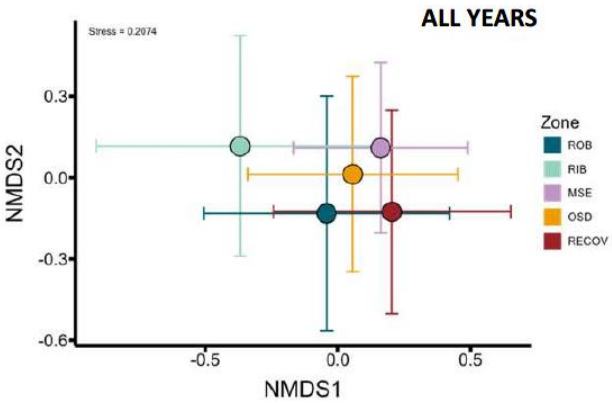
NMDS2 – related to increasing metals and/or PACs

ROB – Reference Outside
RIB – Reference Inside
MSE – DS maniple input @ FMM
OSD – within & DS OS development
RECOV – far DS OS development

Classification: Protected A

Current State: Mainstem Athabasca River





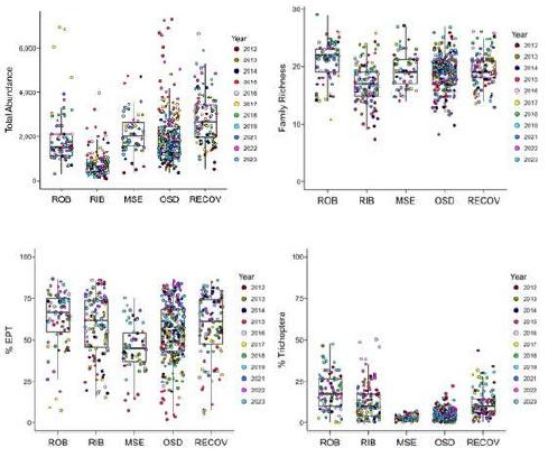
One-way PERMANOVA	
Zone	**p < 0.001**

Pairwise PERMANOVA	
ROB vs RIB	**p < 0.001**
ROB vs MSE	**p < 0.001**
ROB vs OSD	**p < 0.001**
ROB vs RECOV	**p < 0.001**
RIB vs MSE	**p < 0.001**
RIB vs OSD	**p < 0.001**
RIB vs RECOV	**p < 0.001**
MSE vs OSD	**p < 0.001**
MSE vs RECOV	**p < 0.001**
OSD vs RECOV	**p < 0.001**

ROB – Reference Outside
RIB – Reference Inside
MSE – DS maniple input @ FMM
OSD – within & DS OS development
RECOV – far DS OS development

Classification: Protected A

Current State: Mainstem Athabasca River



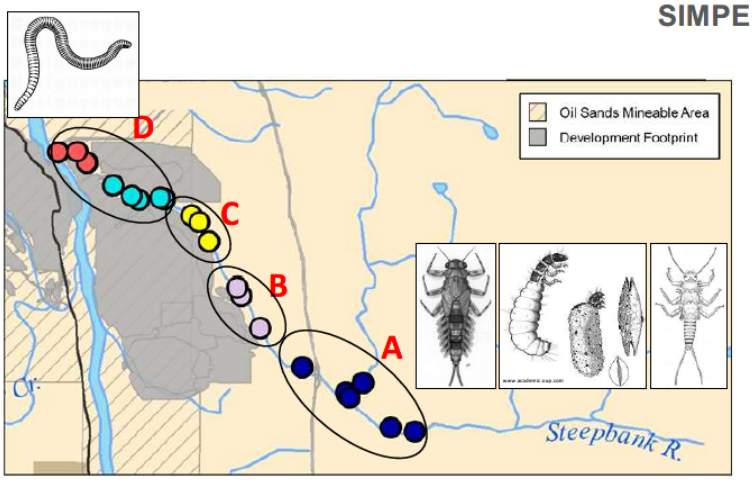
One-way ANOVA p<0.001

Lower Athabasca River

- Similar to Tributaries BMI communities in the Lower Athabasca River have many pollution sensitive taxa, such as mayflies, stoneflies and caddisflies (i.e., Ephemeroptera, Plecoptera and Trichoptera (EPT));
- Compared to reference areas, abundance of BMI was higher in regions of oil sands development, municipal sewage effluent, and sites of recovery. The increase in abundance in these areas was largely due to increases in pollution tolerant taxa, such as midges and worms;
- The proportion of pollution sensitive caddisflies were reduced in areas of oil sands development and municipal sewage compared to reference and recovery areas in the Athabasca River;
- These changes in BMI indicators have been associated with higher concentrations of metals, total polycyclic aromatic hydrocarbons, and nutrients in the areas associated with oil sands development (M3B-M7C) and municipal sewage effluent (M3).

Classification: Protected A

Current State: Steepbank River 2011-2018



SIMPER (Similarity Percentages; PRIMER v.7)

Reference vs. Test Groups

Plecoptera	Nemouridae	↑ Ref
Trichoptera	Brachycentridae	↑ Ref
	Hydropsychidae	↑ Ref
	Lepidostomatidae	↑ Ref
Annelida	Naididae	↑ Test

Test Groups 1 and 2 vs. Group 3

Ephemeroptera	Baetidae	↓ Test 3
Trichoptera	Lepidostomatidae	↓ Test 3
	Hydropsychidae	↓ Test 3
	Glossosomatidae	↓ Test 3
	Brachycentridae	↓ Test 3

Classification: Protected A

Table 2. Hydrological, biological and chemical data used to assess environmental linkages with invertebrate assemblages (BEST routine). Stressor groups for BEST correlations are as indicated below; dissolved and total metals were assessed independently and water and sediment PACs were combined.

	USEPA PRIORITY CONTAMINANTS (WATER)	PACs (SEDIMENT)
us wetted depth	Antimony dissolved and total	C2 Benz[a]anthracene/chrysene
:h	Arsenic dissolved and total	C2-Fluoranthenes/pyrenes
depth	Beryllium dissolved and total	C3-Benz[a]anthracene/chrysene
epth	Cadmium dissolved and total	C4-Benz[a]anthracene/chrysene
velocity (in riffle)	Chromium dissolved and total	Total PACs
elocity (in riffle)	Copper dissolved and total	USEPA PRIORITY CONTAMINANTS (S
trate size (D_{50})	Lead dissolved and total	Mercury total
nt substrate size	Nickel dissolved and total	Antimony total recoverable
ibededness	Selenium dissolved and total	Arsenic total recoverable
rrounding material size	Thallium dissolved and total	Beryllium total recoverable
	Zinc dissolved and total	Chromium total recoverable
iomass (chl-a)	OIL SANDS METALS OF CONCERN (WATER)	Copper total recoverable
overage cateogry	Aluminum dissolved and total	Lead total recoverable
reamside vegetation	Boron dissolved and total	Nickel total recoverable
r %	Iron dissolved and total	Selenium total recoverable
(WATER)	Molybdenum dissolved and total	Silver total recoverable
al CACO3 (calculated)	Strontium dissolved and total	Thallium total recoverable
ed solids (calculated)	Uranium dissolved and total	Zinc total recoverable
	Vanadium dissolved and total	OTHER CONTAMINANTS (SEDIMENT
dissolved/filtered	OTHER METALS (WATER)	Carbon particulate organic
ssolved/filtered	Barium dissolved and total	Carbon total organic
lved/filtered	Cesium dissolved and total	Calcium total recoverable
olved	Cobalt dissolved and total	Iron total recoverable
olved	Gallium dissolved and total	Magnesium total recoverable
olved	Lithium dissolved and total	Manganese total recoverable
olved/filtered	Manganese dissolved and total	Niobium total recoverable
	Rubidium dissolved and total	Phosphorus total recoverable
WATER)	Titanium dissolved and total	Potassium total recoverable
organic (calculated)	Yttrium dissolved and total	Sodium total recoverable
lved organic	Zirconium dissolved and total	Sulphur total recoverable
culate organic	PACs (WATER)	Tin total recoverable
al (calculated)	Naphthalene	Titanium total recoverable
al dissolved	Phenanthrene	Zirconium total recoverable
ticulate	Total PACs	
solved		
otal		
otal dissolved		
particulate (calculated)		
iltrable		

Classification: Protected A